

The 1988 Goddard Space Flight Center Battery Workshop

T. Yi, Editor
NASA Goddard Space Flight Center
Greenbelt, Maryland

Proceedings of a workshop held at
NASA Goddard Space Flight Center
Greenbelt, Maryland
November 1-3, 1988

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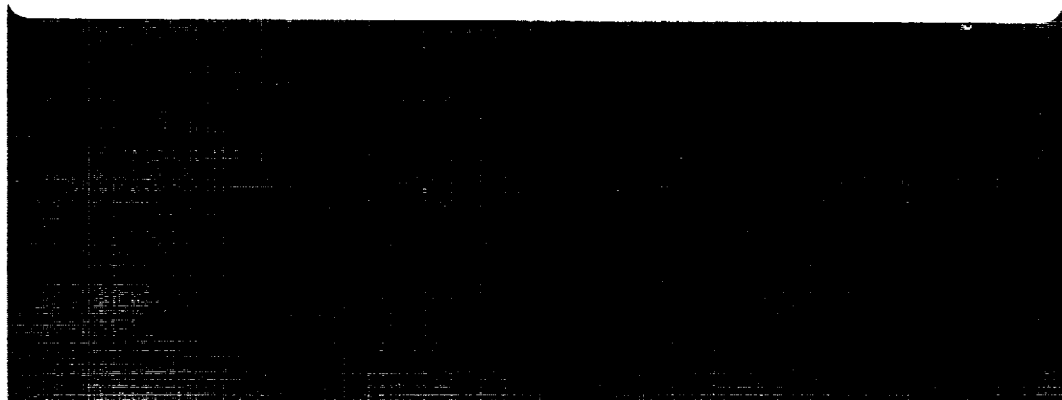
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Scientific and Technical
Information Office

1993



PREFACE

This document contains the proceedings of the 21st annual Battery Workshop held at Goddard Space Flight Center, Greenbelt, Maryland on November 1-3, 1988. The Workshop attendees included manufacturers, users, and government representatives interested in the latest developments in battery technology as they relate to high reliability operations and aerospace use. The subjects covered included battery testing methodologies and criteria, life testing of nickel-cadmium cells, testing and operation of nickel-hydrogen batteries in low earth orbit, and nickel-hydrogen technology issues and concerns.

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Chair: J. Smithrick, NASA/LeRC

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INTRODUCTION

Thomas Y. Yi
Goddard Space Flight Center

I would like to thank you for your continuing interest in the annual NASA Battery Workshop. We sincerely hope that the 1988 Workshop was as informative and enlightening as the past Workshops.

The first day was devoted to the presentations and discussion by the task groups that were formed this summer at the NASA sponsored Nickel-Cadmium Gates Cell Mini-Workshop at the Marshall Space Flight Center addressing recent test failures of the Gates Aerospace Batteries nickel-cadmium cells. Seven different task groups reported at the 1988 Workshop with the goal of improving the reliability of the aerospace nickel-cadmium cells. The task groups reported on 1) uniformity of the tests; 2) uniformity of the destructive physical analyses; 3) separator test and criteria; 4) plate issues; 5) future cell design; 6) evaluation of the on-ground life cycle data; and 7) quality oversight. I want to thank and congratulate the task group members for their effort and work in bringing their findings to the aerospace battery community.

The workshop continued with the NiCd session in the second morning with presentations on the nickel-cadmium cell/battery life testing. The 1988 Workshop was concluded with a full day's worth of presentation on the nickel-hydrogen cell/battery technology, covering simulated life cycle testing, component discussions, and current issues/concerns.

We would like to thank all the people that helped making the 1988 Workshop a success. We would like to thank the attendees, presenters, session chairmen and especially the task team members for the time and effort they have put in, for making the Workshop an active forum for discussion of aerospace cells and batteries.

GATES AEROSPACE BATTERIES PRESENTATION

M. Harrison, G.Klein, and L. Tinker

Gates Aerospace Batteries

Gainesville, FL

November 1-3, 1988

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Aerospace Batteries

Taking Charge

November 1-3, 1988

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Aerospace Batteries Taking Charge

- **Gates Aerospace Batteries**
- **Quality Assurance**
- **Product/Separator**
- **Taking Charge**



Aerospace Batteries New Business

- **Heritage and Autonomy**
- **Organization**
- **Mission**

Aerospace Batteries

Heritage and Autonomy

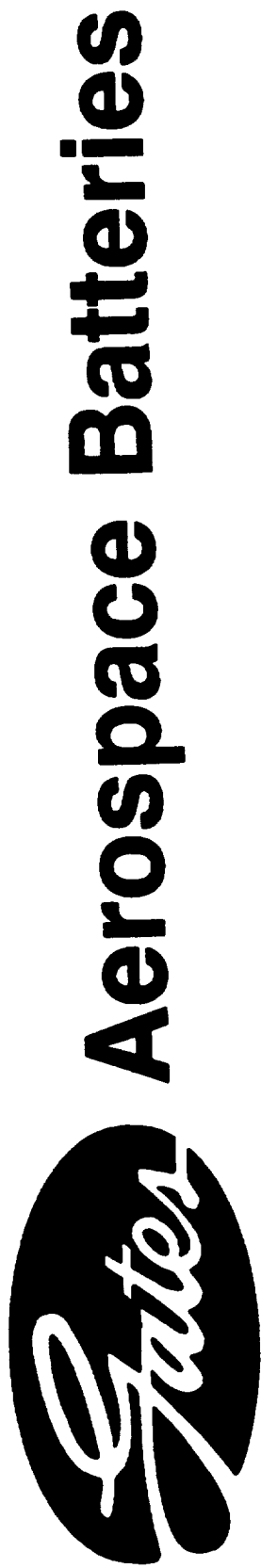
- **Gates Corporation**
 - Focus on Rubber and Batteries
- **Gates Energy**
 - World Leader in Rechargeable Batteries
 - Sealed Lead; Sealed Nickel Cadmium
 - Commercial Products - Household Names
 - GEP Denver: General Electric
- **Autonomous Gates Aerospace Batteries**



Aerospace Batteries Organization

General Manager - Reports to President
GE
Manufacturing - Nickel Cadmium
- Nickel Hydrogen
Quality Assurance - Cell Production
- Test

Test Unit
Engineering
Materiel
Finance
Sales



Mission

To Be The Best . . . !



Aerospace Batteries Taking Charge

- **Autonomous**
- **Organized**
- **Under Control**
- **Directed and Managed to Serve Customers**
- **Future Is Predicated**
 - **Quality of Design**
 - **Quality of Production**
 - **Quality of Test**
 - **Quality of Quality**

“To Be The Best. . .”



Gates Aerospace Batteries

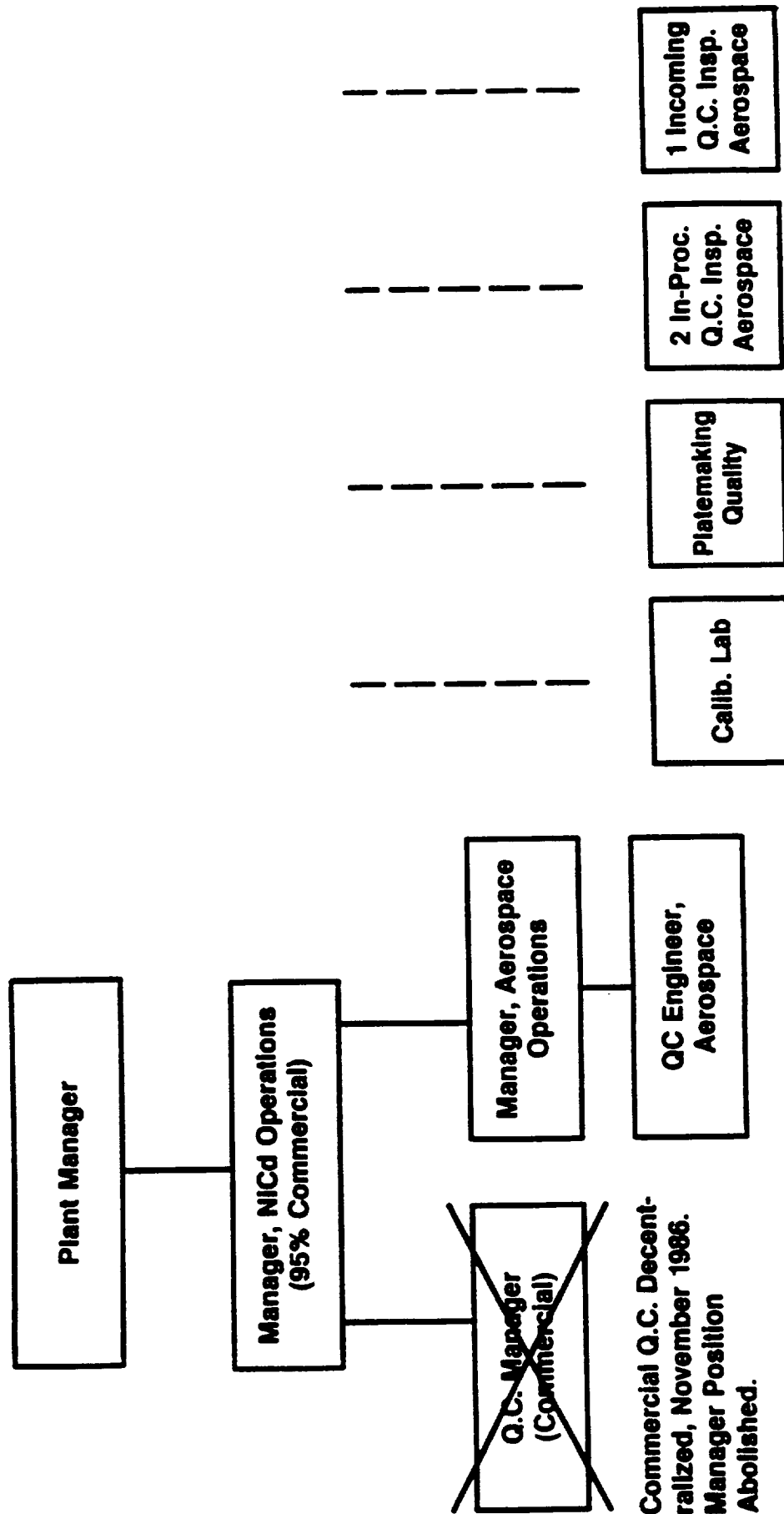
**Product Assurance Improvements
Presented to NASA Goddard
Annual Workshop**

November 1, 2, 1988

Agenda

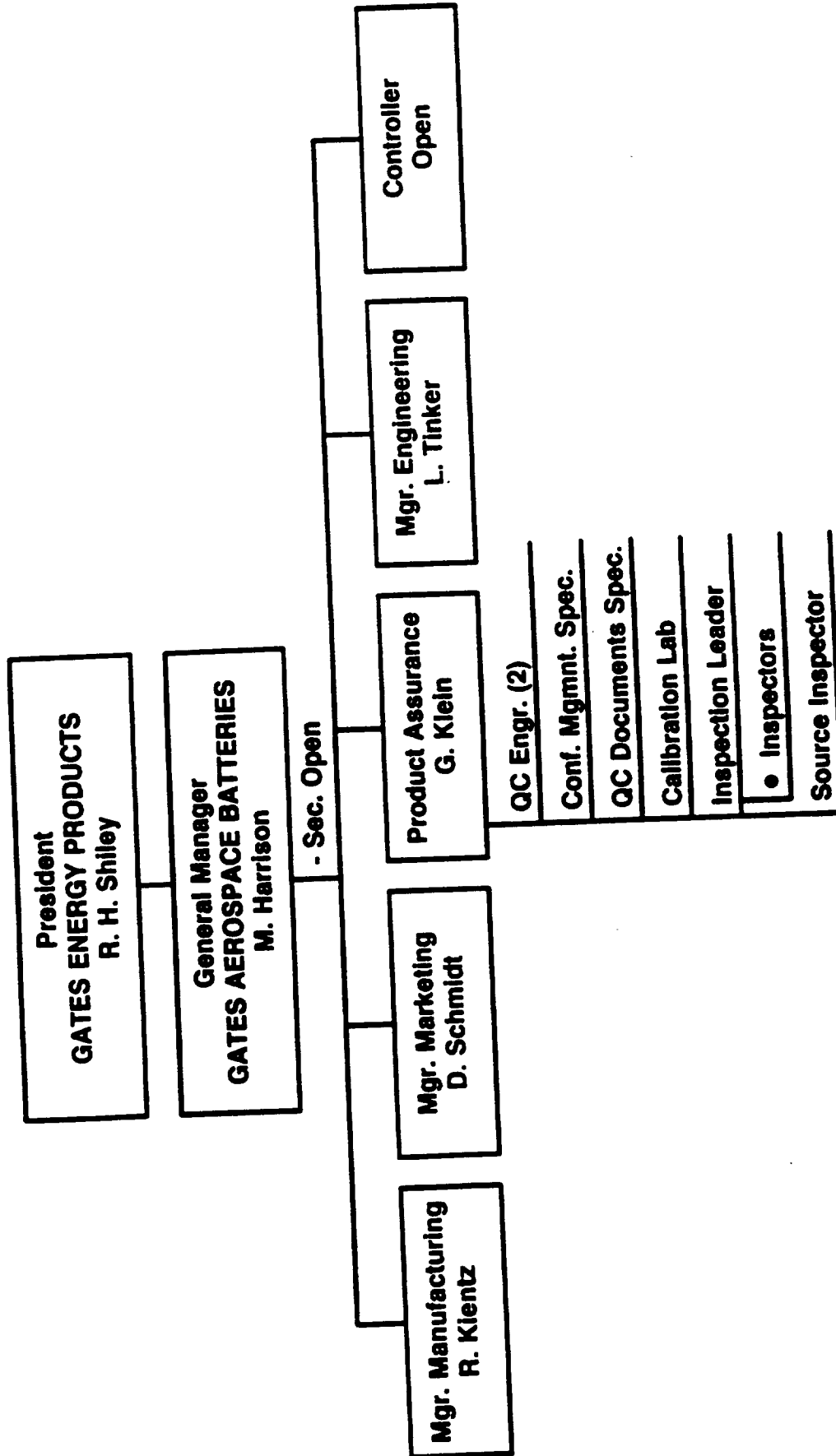
- **1986-1988 Quality Improvements**
- **Transition of Quality Control Engineering to Full Product Assurance Department**
- **Recent Growth of Quality Personnel**
- **Recent Quality Issues**
- **Corrective Actions**
- **Summary**

November, 1986 - GE/BBD



Autonomous Organization: Gates Aerospace Batteries

Aug. 15, 1988



Bottom Line

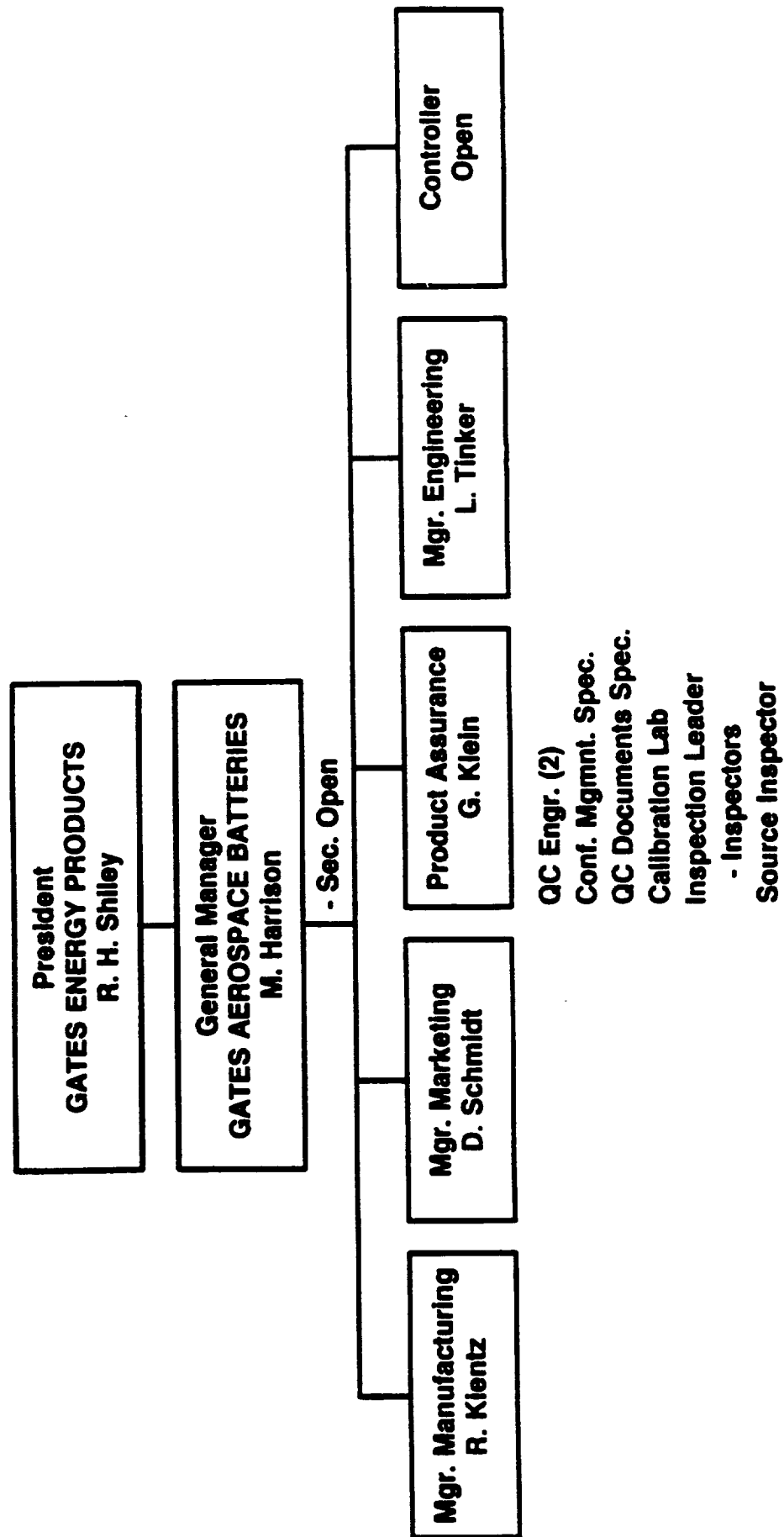
- **Gates Aerospace Batteries Is Emerging from a Manufacturing Facility Under GE/BBD to a Full Service, Customer Oriented Aerospace Facility Under Gates Energy Products**

Quality Issues at Gates Energy Products

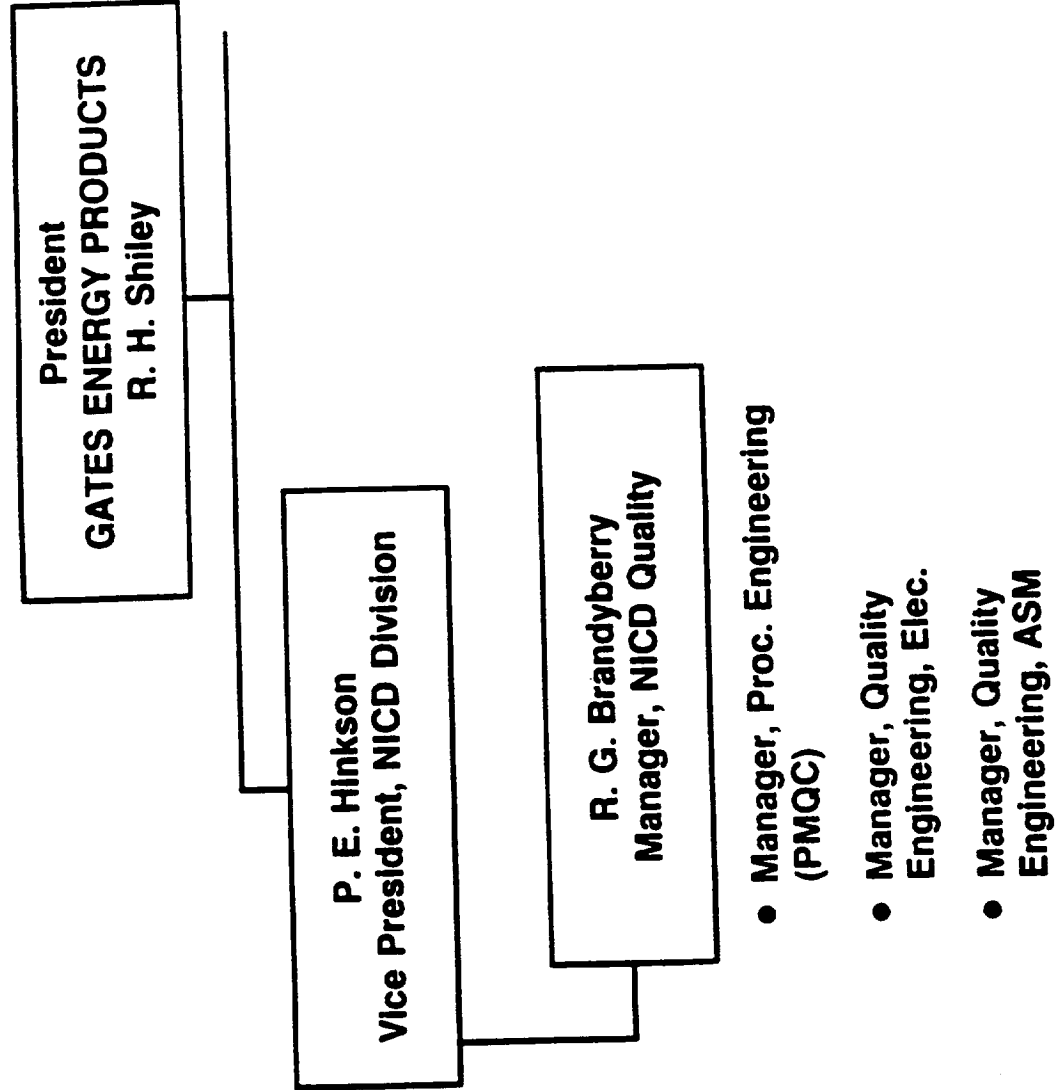
- **No Centralized Quality Organization to Affect Clearly Defined Responsibility, Authority and Accountability**
- **GIDEP Alert (Electrodes & Separator)**
- **Acceptance Testing**

Centralized Quality:

Autonomous Organization: Gates Aerospace Batteries



Centralized Quality: Gates Energy Products



GIDEP Alert:

Dr. Lawrence Tinker: Electrode & Separator

- **Performance & Reliability - Not Traditional Quality Control**
- **Fall Out: (1) Method C - Specific Area
(2) General Platemaking Audit**

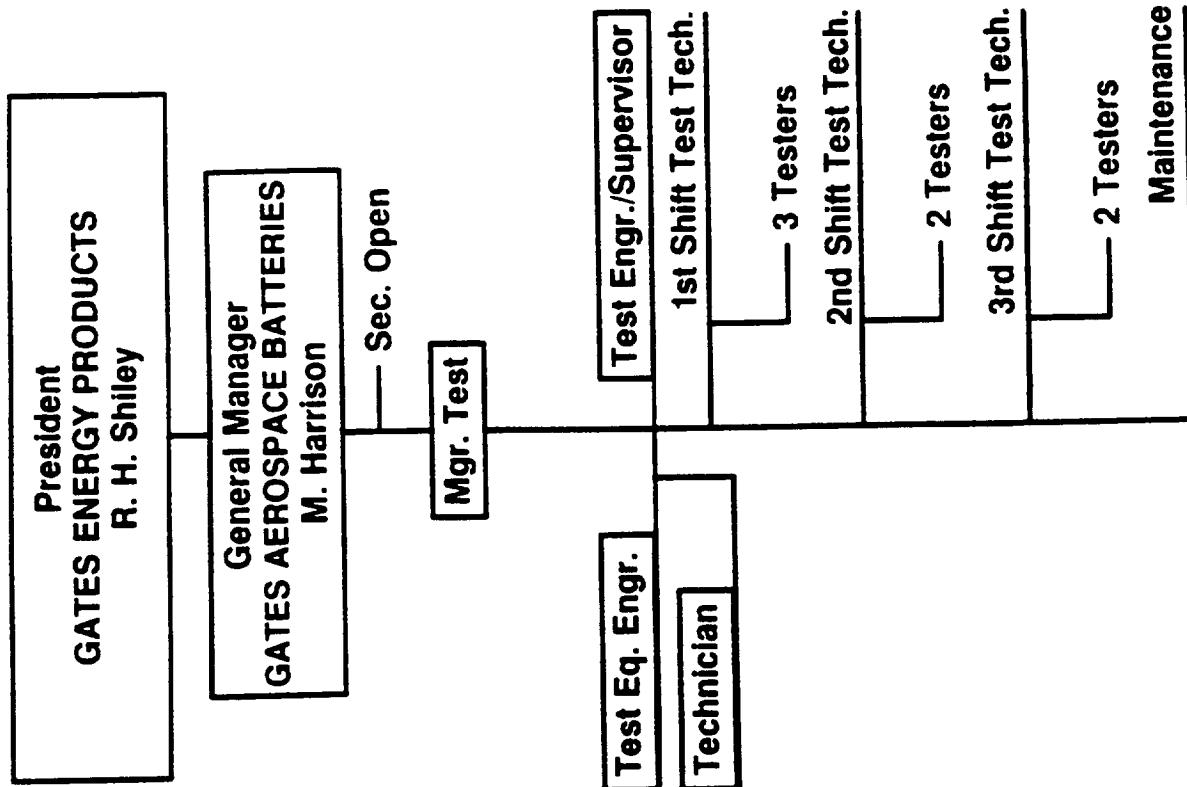
Status: Method C:

- **Immediate Action: Station Control 701-93, July 8, 1988**
- **Corrective Action: (1) Definition of Root Cause of the Deficiency**
 - (a) Communication**
 - (b) True Vendor Status of G.E.P. Platemaking to G.A.B.**
- (2) Action Taken: "Charter Document: October 2, 1988"**
- **Close Out: Entire Customer Base Must Approve "Charter Document:**

Status: Platemaking Audit:

- **Undefined Role of Commercial, Centralized Quality**
- **Customer Acceptance of “Charter Document”,
October 31, 1988**
- **Immediate Actions:**
 - Centralized Quality Proposed**
 - Source Inspection Proposed**
 - Charter Document Definition**
- **Corrective Actions: (1) Charter Document Completed
10/2/88**
 - (2) Source Inspection by 12/31/88**

Acceptance Testing: Staff Level



Status: New Test Unit: Randy Kientz:

- **Technical Personnel on All Three Shifts**
- **Permanent Positions - Interviews Have Begun**
- **Will Define Responsibility, Authority and Accountability**

Status: New Test Unit: Glenn Klein:

- **Proposed Off Shift Inpection in Mid July**
- **Hired Two Inspectors Mid August**
- **Inspectors Now in Training for Placement
by November 15, 1988**

Conclusion: Three Major Areas of Concern:

- **Centralized Quality**
- **GIDEP Alert**
 - **Method C**
 - **Platemaking Audit**
- **Acceptance Testing**

Conclusion

Major Changes

- **Autonomous G.A.B. with Staff Level Product Assurance**
- **Commercial G.E.P. Has Established Centralized Quality Organization**
- **G.A.B. Has Completed Method C but Needs Customer Approval**
- **G.A.B. Is Resolving Platemaking Issues**
- **G.A.B. Will Institute Source Inspection**
- **New Test Unit Will Resolve Their Issues**

Gates Aerospace Batteries Is Emerging from a Classical Manufacturing Facility Under General Electric to a More Responsible and Flexible Aerospace Facility and Seek Your Continued Guidance in Establishing an Alliance and Partnership.



Aerospace Batteries

Engineering Overview

**Presented at
NASA/GSFC Battery Workshop**

November 1-3, 1988

Topics

- **Background**
- **Cells Investigated and Results**
- **Electrolyte Management and Separator**
- **Qualification Tests of 2536 Separator**
- **New Separator Program**

Background

- **Several Issues Concerning GAB Cells Have Surfaced During Past Year**
 - **Performance Anomalies and Failures in Separator Requalification Tests**
 - **Apparent Early Degradation of Freudenberg 2505 Separator**
- **Resulted in Issuance of Letter by GAB to Customers Regarding Cells with 2505 Separator**
- **Resulted in GIDEP Alert Issued by NASA/GSFC**
- **GAB Has Investigated These Issues Extensively During This Year**

Summary of Cells Investigated

- 122 Cells Through DPA/CMA During Past Year
 - Does Not Include Cells After Pre-Charge
- 97 Cells with 2505 ML Separator
25 Cells with 2536 Separator
- Cells Represented:
 - 55 Plate Lots
 - 27 Catalog Numbers
 - 12 Customers
 - 5 Separator Lots
 - 25 Separator Rolls
 - 72 Cells from Lot 30158
 - 46 Cells from Rolls 1-5LR037

Summary of Results from Tests

- 31 Cells with Overcharge Protection Factor < 4.0
 - 22 from Cells with 2505 (5 from Crane Test Cells)
 - 9 from Cells with 2536 (8 from Crane Test Cells)
- 26 Cells with Excessive Cadmium Migration
 - 9 from Cells with 2536 (8 from Crane Test Cells)
 - 7 Shorted Cells from This Group, 3 with 2505 and 3 with 2536 from Crane Test Cells
- 17 Cells with Some Amount of Separator Sticking
- 21 Cells with Poor Separator Strength (All 2505 Cells)

Summary of Results (Continued)

- Cells from Rolls 1-5LR037

Roll	# Cells	Excess Cadmium Migration	Poor Separator Strength	Overcharge Factor < 4.0
1	5	3 (Crane)	3 (Crane)	3 (Crane)
2	6	0	0	0
3	17	9	7	5
4	14	1	3	5
5	4	1 (Crane)	3	2

- Cells with 2505 from Outside of Five Suspect Rolls
 - 3 Cells with Excess Cadmium Migration
 - 5 Cells with Poor Separator Strength
 - 7 Cells with Overcharge Factor < 4.0

Separator Comparison

2505 ml 2536

Nylon Type 100% Nylon 6 67% Nylon 66
33% Nylon 6

Weight, g/m²

60 ± 8

80 ± 5

Thickness, Mils
(Compressed)

7 - 10

7 - 9

Electrolyte Absorption
% of Dry Weight

400 Minimum
(700-900 Typical)

300 Minimum
(300-400 Typical)

Air Permeability
CFM/ft²

200-300

100-200

Bonding Method

ZnCl₂

Hot Inert Gas

Electrolyte Management

- **Both Positive and Negative Plate Characteristics Play Critical Role in Electrolyte Management**

Positive Electrode

- **Sinter Strength Important in Reducing Swelling**
- **Nickel Attack Needs to Be Controlled to Provide Strength and Maintain Porosity**
- **Loading Levels Need to Be Controlled to Reduce Swelling, Reduce Pore Blockage, Reduce Electrolyte Redistribution**

Negative Electrode

- **Loading Levels Should Be Controlled to Reduce Cadmium Migration**
- **Must Maintain Adequate $-/+$ Ratio, Precharge, and Overcharge Protection**
- **Critical in Maintaining Low Oxygen Pressure During Overcharge**

Electrolyte Management

- **Greater Electrolyte Levels Enhance Life Characteristics**
 - **Greater Reserve for Plate Swelling**
 - **Greater Thermal Conductivity - Reduces Heat Build-Up**

Qualification Tests of 2536 Separator

- **NASA Sponsored 50 Ah Cells**
 - **No Catastrophic Failures in Testing**
 - **Some Anomolous Voltage Behavior with Both Separators**
 - **Cells Remain on Test in LEO and GEO Cycles**
 - **Over 15,000 Cycles Completed in LEO Orbit with 2536 Separator**
 - **More Than 6 Seasons in GEO Completed (Real Time)**

Qualification Tests of 2536 Separator

- **PERFORMANCE IN MARTIN MARIETTA PROGRAM**
 - 10 Ah Cells, 27% DOD, LEO, 20 °C
 - >10,000 Cycles to Date
 - No Distinguishable Differences Between 2505 and 2536 Cells
- **PERFORMANCE IN GE-ASTRO SPACE PROGRAM**
 - 26.5 Ah Cells, 25% DOD, LEO, 4 °C
 - Completed 9600 Cycles to Date
 - Evidence of Anomalous Behavior in Both Types of Cells
 - Shorts in Both Types of Separator Cells
 - Remaining Cells Performing Well

Qualification Tests of 2536 Separator

- **Joint Air Force/Navy Program**
 - **Four Types of Cells from 26.5 to 50 Ah Cells**
 - **All Failures in LEO Test Cells**
 - **Failures Consistent with Accelerated Separator Dry Out Due to Overall Plate Issues**
 - **GEO Packs Still on Test with >10 Accelerated Seasons**

Existing Cells Using 2536 Separator

- **Plate Characteristics Should Be Reviewed for Porosity/Pore Volume and Loading Level**
- **Electrolyte Levels in Activated Cells Should Be Examined and Compared with Similar Cells Using 2505 mL.**

Existing Cells Using 2536 Separator

- **Positive Plates Should Be Replaced if Porosity $< 30\%$**
 - **Porosities Below 30% Indicate Low Nickel Attack and/or High Loading Levels**
 - **These Characteristics Lead to Reduced Initial Electrolyte Levels and Accelerate Electrolyte Redistribution**
- **Negative Plates Not as Critical but Porosity Should Be Maximized While Maintaining Adequate $-/+$ Ratio**

New Separator Program

- Separator Samples Received from Two Suppliers
 - Three Samples from Freudenberg
 - One Sample from Kendall
- Freudenberg to Provide One Additional Sample
- Sample Characteristics

		Weight g/m ²	Thickness mils	KOH Absorption % of Dry Weight
Freudenberg	A	64	10.9	570
	B	69	16.4	1760
	C	52	11.3	2650
Kendall		65	10.5	500

Separator Evaluation Program

Initial Tests

- **Samples Are Being Processed Through Normal Incoming Inspection Tests**
- **Samples Are Being Tested in Oxidative Degradation Tests**
- **Most Promising Candidate(s) Will Be Selected for Complete Cell Tests**
- **Both Current 2536 and New Sample(s) Will Be Tested**

Separator Evaluation Program

Design Parameters

- **Cell Size to Be Used Is 27AB07 Type Cell**
- **Positive and Negative to Conform to GAB Design Parameters for Loading and Porosity**
- **Negative Will Be Teflon Treated**
- **C Rate Current Density Will Be 20 mA/cm²**
- **Cells Will See Pre-ATP and Limited ATP Testing**
- **Short Term Evaluation Test to Be Used**

Separator Evaluation Program Test Program

- **Three Cells of Each Type Separator**
- **Leo Cycling, 30 Minute Discharge, 60 Minute Charge**
- **50% DOD Based on Nameplate Capacity**
- **Initial C/O Ratio of 1.05**
- **Temperature: 20°C**
- **At 1000 Cycles Remove One Cell of Each and Do Complete DPA/CMA to Examine Separator and Plate Changes**

Qualification Testing Customer Involvement

- **GAB Has Limited Life Test Capability**
- **Each Customer Has a Different Mission Profile**
- **Impractical for GAB to Test Many Different Cycle Regimes**
- **GAB Encourages Customers to Initiate Their Own Qualification and Life Test Programs to Support a Replacement Separator**
- **GAB Wants to Work with Customers to Satisfy Needs and Provide Reliable Products**

Total Customer Satisfaction

PRIORITY ONE

MEMORANDUM

DATE: October 27, 1988

TO: Glenn Klein

FROM: Gregg Brandyberry *Gregg*

RE: Position Statement

In response to our discussion of October 24th, 1988, I thought it would be appropriate to provide Gates Aerospace Battery with a position statement detailing the philosophical and structural quality changes currently transpiring within Gates Energy Products, Inc.

POSITION STATEMENT

Gates Energy Products, Inc. is committed to supplying Gates Aerospace Battery with highly consistent plate product through cost efficient quality manufacturing. That is; providing our valued customer with:

The Right Quantity...
At The Right Time...
Of The Right Quality...
For The Right Cost...

This will be achieved by the development and implementation of a three fold process.

I. Restructuring of the Formal Quality Entity

All quality functions including a) purchased material control, b) process/product audit, c) process (PMQC) engineering, d) product test labs, and e) customer support services now report to the Manager of NiCd Quality; a staff position reporting directly to the Vice President of Manufacturing. This structure will elicit a broadbased, yet focused, quality system providing product/process maintenance, continuous improvement and cultural direction to insure that leading edge quality/manufacturing is inherent in the 1990's and beyond.

II. Full Implementation of Traditional Quality System

Policies and procedural documentation will be developed and implemented where substandard in the quality system elements of:

- a. Purchased material control
- b. Supplier surveillance
- c. Specifications change and control
- d. Gauge calibration and gauge R&R evaluation
- e. Process/product instructions and inspection procedures
- f. Control of non-conforming product
- g. Problem identification and resolution
- h. Final test and audit
- i. Lot control/traceability

III. Implementation of "Preventative Manufacturing Quality Control" Philosophy (PMQC)

Preventative Manufacturing Quality Control is a philosophy/culture developed to support a manufacturing system which allows both quality and productivity to occur with balanced equivalence.

In theory, PMQC integrates both manufacturing and quality into one homogeneous system. PMQC is extremely production operator oriented and includes all "preventative" manufacturing techniques used to control and/or verify production processes. PMQC techniques include:

- a. Advanced quality planning
- b. Failures mode effects analysis
- c. Statistical process control
- d. Design of experiments
- e. Cause/effect problem analysis
- f. Process syntactics

PMQC involves continually analyzing an entire manufacturing structure, identifying "pressure points" at which potential failures could occur, and implementing preventative process controls at these "pressure points" to prevent the occurrence of non-conformance.

PMQC is driven by the process engineering function. PMQC reduces the need for traditional "after the fact" inspection programs. True PMQC techniques meet the following criteria:

- a. Does not hinder production
- b. Is based upon prevention
- c. Does not create inspection ques
- d. Is operator oriented (some exceptions)
- e. Identifies and resolves root causes of non-conformance

This summary, while not all inclusive, provides a brief outline of the future direction of the NiCd Division Quality Program.

I am convinced that adherence to this program will result in ongoing continuous improvement of process variability and ultimately product performance.

RGB/kdg4

cc: Paul Hinkson
Mike Harrison

SESSION I

TASK GROUP PRESENTATION & DISCUSSION

Chairman: G. Halpert, JPL

INTRODUCTION OF TASK FORCE GROUPS

G. Halpert, JPL
N. Schulze, NASA/HQ

November 1-3, 1988

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STRAWMAN DEFINITION OF AN AEROSPACE QUALITY CELL

OPERATIONAL

- COMPLETE 2 YEARS OF LOW-EARTH ORBIT CYCLING
 - 40% DEPTH-OF-DISCHARGE
 - TEMPERATURE AT 20°C
 - MAINTAIN END-OF-DISCHARGE VOLTAGE > 1.00V/CELL
 - END-OF-CHARGE VOLTAGE $\pm 8\text{mV}$ ON BATTERY BASIS
 - WITHOUT RECONDITIONING OR FAILURE
- SATISFACTORILY COMPLETE REQUIRED NASA ACCEPTANCE TESTS

CELL DESIGN

- MANUFACTURED TO NASA STANDARD SPECIFICATION
 - > 40% POSITIVE PLATE POROSITY
 - > 3CC/Ah OF ELECTROLYTE
 - 10mA/cm² OF POSITIVE PLATE AT THE C/2 RATE

PRESENT CELL DESIGNS INADEQUATE FOR

LONG TERM LEO MISSIONS

- PLATE LOADING HIGH
- PLATE AREA LIMITED --- $10\text{mA}/\text{cm}^2$
- ELECTROLYTE VOLUME LOW
 - PLATE POROSITY
 - SEPARATOR ABSORPTION

RELIABILITY IMPROVEMENTS

- **UNIFORMITY OF TEST**
- **DESIGN CELLS FOR APPLICATION**
- **MATERIALS ADEQUATE**
- **QUALITY IMPOSED**
- **ANALYSIS/UNIFORM DPA**
- **TESTING/MODEL**
- **METHOD OF CHARGE CONTROL**
 - **RATE**
 - **TEMP**

ATTACHMENT 4

TASK FORCE GROUPS

Uniform Core Tests and Acceptance Test Quality

Lead: T. Yi/GSFC
Members: G. Klein/GEP, S. Donley/Aerospace, K. Schwer/MDAC,
D. Webb/MMC, C. Koehler/Ford, P. Olbert/Ball,
G. Halpert/JPL

Uniform Destructive Physical Analysis (DPA)

Lead: W. Scott/TRW
Members: M. Earl/Comsat, L. Tinker/GEP, H. Lewis/NWSC,
S. DiStefano/JPL, A. Zimmerman/Aerospace,
D. Maurer/GE-EW

Separator Acceptance Test And Criteria

Lead: M. Manzo/LeRC
Members: L. Christensen/FN-USA, G. Klein/GEP, G. Methlie,
A. Zimmerman/Aerospace

Plate Issues

Lead: D. Maurer/AT&T,
Members: C. Lurie/TRW, R. Kientz/GEP, C. Koehler/Ford,
H. Thierfelder/GE-VF

TASK FORCE GROUPS (Cont.)

Future NiCd Cell Design

Lead: S. Gross/Boeing
Members: L. Thaller/LeRC, L. Tinker/GEP, D. Maurer/AT&T,
D. Pickett/HAC, G. Methlie, G. Halpert/JPL

Evaluation of NWSC Data - Recommend Near Term Cell Design Fixes

Lead: B. Billerbeck/MRJ
Members: G. Morrow/GSFC, C. Garner/NRL, S. Gaston/GE-EW,
D. Mains/NWSC, K. Clark/JPL, L. Tinker/GEP

Quality Oversight Task Group

Lead: C. Lurie/TRW
Members: N. Schulze/NASA Hq, P. Olbert/Ball, T. Yi/GSFC
J. Dunlop/Consultant, B. Otzinger/Rockwell,
D. Sedgwick/JPL, W. Hwang/Aerospace

MESSAGE FOR PROJECTS

- CHEMICAL STORAGE DEVICE
- COMPLEX CHEMISTRY
- APPROPRIATE DESIGN
- CONSIDER APPLICATION
- REAL TIME TESTING
 - TIME CONSUMING
 - COSTLY
- RELIABILITY

UNIFORM CORE TESTS AND
ACCEPTANCE TEST QUALITY

THOMAS YI, NASA/GSFC
TASK GROUP PRESENTATION
1988 NASA/GSFC BATTERY WORKSHOP
NOVEMBER 1, 1988

**UNIFORM CORE TESTS AND
ACCEPTANCE TEST QUALITY**

Members:

T. Yi	NASA/GSFC
G. Klein	GAB
S. Donley	Aerospace
K. Schwer	MDAC
D. Webb	MM
C. Koehler	FAC
P. Olbert	Ball
G. Halpert	JPL

OBJECTIVES:

Develop a common acceptance test procedure and associated quality instructions which can be agreeable to all cell users and manufacturer

PROS:

Since GAB needs to adhere to only 1 standard ATP requirements, its test reliability and quality assurance should improve.

The ATP data can form the basis of a "common data pool" that can be available to all users.

CONS:

Loss of individual databases if a standard ATP is implemented.

Standard ATP may not be compatible with individual spec requirements.

Additional tests may be required for certain missions.

PLAN

- 1) **Identify ATP's in place at GAB.** **EASY**
- 2) **Identify common test steps.** **EASY**
- 3) **Identify and recommend test steps that should form the uniform ATP.** **EASY**
- 4) **Agree on the sequence of test steps.** **HARD**
- 5) **Agree on the test description, and associated data parameters.** **FAIRLY EASY**
- 6) **Identify additional tests: Short-term stress cycling, "common data pool" type tests.** **HARD**

ATP's CONSIDERED

- **NASA Standard Design**
- **Air Force Common Data Pool recommendation**
- **14 ATP's from various primes**

<u>NASA Std</u>	<u>AF Common Data</u>	<u>ATP 149/156</u>	<u>ATP 213/215</u>
23°C Cap	25°C Cap	10°C Cap	Cap Stab.
30°C Cap	0°C Cap	0°C Overchg	23°C Overchg
0°C Overchg	0°C Overchg	Pulse Load	
Low Rate Eff.	Chg Retention		
23°C Cap			
Chg Retention			
Impedance			
Pulse Load			

<u>ATP 313</u>	<u>ATP 423</u>	<u>ATP 431</u>	<u>ATP 433</u>
0°C Overchg	25°C Overchg	25°C Overchg	22°C Cap
25°C Cap	25°C Cap	25°C Cap	5°C Cap
0°C Cap	0°C Overchg	10°C Cap	5°C Overchg
10°C Cap	10°C Cap	0°C Overchg	35°C Cap
Pulse Load	Pulse Load	Pulse Load	Pulse Load
Chg Retention	Chg Retention	Chg Retention	Impedance
	Impedance	Impedance	Chg Retention

<u>ATP 436</u>	<u>ATP 514A</u>	<u>ATP 914</u>	<u>ATP 919</u>
25°C Overchg	30°C Overchg	25°C Cap	21°C Overchg
25°C Cap	0°C Cap	10°C Cap	10°C Cap
0°C Cap	0°C Pulse	-1°C Cap	0°C Overchg
0°C Overchg		21°C Overchg	-10°C Cap
Pulse Load		-1°C Overchg	Impedance
Chg Retention		Pulse Load	Chg Retention
Impedance		Impedance	
		Chg Retention	

<u>ATP 1105</u>	<u>ATP 1416</u>	<u>ATP 1611</u>
22°C Cap	20°C Cap	22°C Cap
7°C Cap	10°C Cap	22°C Cap
5°C Overchg	0°C Cap	0°C Cap
35°C Cap	Chg Retention	0°C Cap
Pulse Load	Impedance	0°C Overchg
Impedance		Chg Retention
Chg Retention		

PRESENT CRITERIA/TOLERANCES IN THE ATPs

Temp:	$\pm 3^{\circ}\text{F}$ to $\pm 6^{\circ}\text{F}$
Max Pressure:	60 psig to 80 psig
Room Temp:	20°C, 21°C, 22°C, 23°C, 25°C
High Temp:	30°C, 35°C
Cold Temp:	-1°C, 0°C, 5°C, 7°C
Pulse Load:	up to 5C rate
Chg Ret Volt:	1.15V, 1.16V
Impedance:	3mΩ to 10mΩ

RECOMMENDATIONS:

- 1) Implement common tolerances:
 - e.g., temp $\pm 4^{\circ}\text{F}$, max pressure 60 psig, etc.

- 2) Core ATP (at minimum, include)
 - Room temp capacity - 20°C
 - High temp capacity - 30°C
 - Cold temp overchg - 0°C
 - Room temp capacity - 20°C
 - Pulse load/chg retention/impedance

However, the order of these tests as well as the test description needs to be further studied.

- 3) Short-term test
 - e.g., common 500-cycle test

- 4) Air Force Common Data Pool type electrical test
 - conditioning cycle - 25°C
 - capacity checks - 25°C (repeat until last 2x agree)
 - overchg and capacity - 0°C
 - capacity - -10°C
 - charge retention

- 5) Depository of All Data
 - e.g., ATP data at GAB, Other data at Crane (?)
 - Data to be available for all; data not identified by program

ACCEPTANCE TEST QUALITY

- Automated testing is needed ASAP
 - GAB in process of automating the test area
- Fail-safes need to be implemented in the testing areas ASAP
 - Fail-safes currently planned and being installed at GAB
- Better Shop quality instructions needed
 - ASP-001 written and implemented at GAB

UNIFORM DPA COMMITTEE INTERIM REPORT

NASA GSFC BATTERY WORKSHOP

1 - 3 NOVEMBER 1988

W.R. SCOTT

UNIFORM DPA COMMITTEE - REPORT

COMMITTEE MEMBERSHIP

S. DI STEFANO	JET PROPULSION LABORATORY
M. EARL	COMSAT LABORATORIES
H. LEWIS	NWSC (CRANE, IN)
D. MAURER	GE - EW
L. TINKER	GATES ENERGY PRODUCTS
A. ZIMMERMAN	AEROSPACE CORPORATION
W. SCOTT (LEAD)	TRW

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RATING SHEET FOR EXISTING TESTS

NON-CONVENTIONAL TEST METHODS

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PROPOSED DEFINITION OF "DPA" FOR BATTERY CELLS

THE TERM "DPA" AS APPLIED TO BATTERY CELLS SHALL BE DEFINED AS INCLUDING:

- (1) PHYSICAL TESTING AND CHEMICAL ANALYSIS OF CELL COMPONENTS AND MATERIALS BEFORE THEY ARE PUT INTO CELLS, AND AFTER REMOVAL FROM CELLS;
 - (2) ELECTROCHEMICAL ANALYSIS OF ELECTRODES BEFORE THEY ARE PUT INTO CELLS, AND AFTER REMOVAL FROM CELLS; AND
 - (3) ELECTROCHEMICAL ANALYSIS OF ELECTRODES AS PART OF CELLS, WHERE THE ANALYSIS INVOLVES DESTROYING THE CELL AS A UNIT IN THE PROCESS.
- CELL DPA SHALL NOT INCLUDE ELECTRICAL TESTING OF END-ITEM CELLS EXCEPT AS SUCH TESTING MAY BE A PART OF AN OVERALL DESTRUCTIVE TEST PROCEDURE.

PROPOSED NEAR-TERM OBJECTIVES

1. DETERMINE THE DIFFERENT PURPOSES FOR WHICH NICKEL-CADMIUM CELL MATERIALS ANALYSIS AND/OR CELL DESTRUCTIVE ANALYSIS (A) HAS BEEN USED AND (B) SHOULD BE USED.
2. DETERMINE WHERE IN THE NORMAL CELL MANUFACTURING PROCESS AT GATES ENERGY PRODUCTS (GEP) THEY PERFORM MATERIALS AND/OR CELL DESTRUCTIVE ANALYSIS, WHAT THEY ANALYZE, AND WHAT TYPES OF ANALYSES THEY DO AT EACH POINT.
3. DETERMINE WHICH ANALYSIS GEP IS NOW DOING FOR DIFFERENT CUSTOMERS, AND WHAT OTHER TYPES OF ANALYSES GEP IS EQUIPPED TO DO.
4. DETERMINE THE METHOD GEP IS USING TO RECORD RESULTS OF MATERIALS ANALYSIS IN-HOUSE, WHAT DATA IS REPORTED TO CUSTOMERS, AND IN WHAT FORM.
5. RECOMMEND A "CORE" (MINIMUM MANDATORY) SET OF ANALYSES/TESTS (OR MORE THAN ONE CORE SET, IF APPROPRIATE).
6. RECOMMEND ADDITIONAL, OPTIONAL ANALYSES/TESTS TO AUGMENT THE CORE SET(S).
7. DETERMINE WHICH OF THE TESTS GEP IS WILLING TO DO.

UNIFORM DPA COMMITTEE - REPORT

PROPOSED LONGER-TERM OBJECTIVES

- 1. DETERMINE THE METHODS USED BY GEP TO PERFORM THE VARIOUS ANALYSES THEY ARE DOING. IDENTIFY THOSE ANALYSES FOR WHICH THE RESULTS MAY BE METHOD-SENSITIVE OR TECHNICIAN-SENSITIVE.**
- 2. CRITIQUE METHODS USED FOR ANALYSES. PROVIDE IMPROVED METHODS WHERE NEEDED. RECOMMEND RESEARCH ON METHODS WHERE REQUIRED.**
- 3. PROVIDE INTERPRETATION OF RESULTS. PROVIDE CRITERIA/LIMITS OF ACCEPTABILITY FOR DIFFERENT APPLICATIONS.**
- 4. ASSESS THE EFFECTIVITY OF ANALYSES AND TESTS CURRENTLY USED, TO DETECT THE RESULTS OF MANUFACTURING PROBLEMS AND TO ANTICIPATE PERFORMANCE PROBLEMS.**

UNIFORM DPA COMMITTEE - REPORT

COMMITTEE ACTIVITY STATUS

- 0 APPROXIMATELY 40% OF THE NEAR-TERM OBJECTIVES HAVE BEEN ACCOMPLISHED TO
DATE
- 0 APPLICATIONS OF DPA WERE EXAMINED
- 0 ANALYSES AND TESTS PERFORMED BY GATES ENERGY PRODUCTS DURING CELL
MANUFACTURING WERE REVIEWED
- 0 COMMITTEE MEMBERS WERE POLLED ON THE RELATIVE MERITS OF CONVENTIONAL TYPES
OF ANALYSES AND TESTS
- 0 MORE SOPHISTICATED ANALYTICAL METHODS ARE BEING CONSIDERED
- 0 SOME INTERIM RECOMMENDATIONS WERE FORMULATED

UNIFORM DPA COMMITTEE - REPORT

SOME DPA-RELATED ANALYSES AND TESTS NOW DONE ROUTINELY BY GEP

<u>WHERE IN THE PROCESS</u>	<u>WHAT IS ANALYZED/TESTED</u>	<u>PROPERTIES DETERMINED</u>
PLATEMAKING	SITIERED STRIP (UNIMPREGNATED)	THICKNESS
		WEIGHT PER UNIT AREA
		WEIGHT NI PER UNIT AREA
	IMPREGNATED STRIP	WEIGHT PER UNIT AREA
		WEIGHT GAIN (BY IMPREGNATION)
		"HYDRATE" WEIGHT PER UNIT AREA
TRANSITION TO AEROSPACE CELL OPERATIONS	POSITIVE AND NEGATIVE PLATE MATERIAL	WEIGHT PER UNIT AREA
		THICKNESS
		ACTIVE MATERIAL PER UNIT AREA
		WEIGHT NI PER UNIT AREA
		APM LEVEL
		NICKEL ATTACK (POSITIVE ONLY)
		POROSITY (BY CALCULATION)
		CADMIUM OR SILVER AS APPLICABLE
		FLOODED CAPACITY
		STRESS TEST RESISTANCE

SOME DPA-RELATED ANALYSES AND TESTS NOW DONE ROUTINELY BY GEP (CONTINUED)

<u>WHERE IN THE PROCESS</u>	<u>WHAT IS ANALYZED/TESTED</u>	<u>PROPERTIES DETERMINED</u>
INCOMING	SEPARATOR MATERIAL	SEPARATOR ACCEPTANCE TESTS: WEIGHT PER UNIT AREA THICKNESS ELECTROLYTE ABSORPTION
AFTER CARBONATE EXTRACTION OF PLATES	POSITIVE AND NEGATIVE PLATES	SELECTED CHEMICAL CONSTITUENTS VOID FRACTION
AFTER CELL ASSEMBLY, ACTIVATION, AND SETTING OF PRECHARGE	STARTS WITH A WHOLE CELL	TOTAL POSITIVE ELECTROCHEM. CAPACITY TOTAL POSITIVE CHEMICAL CAPACITY TOTAL NEGATIVE CHEMICAL CAPACITY NEGATIVE CHARGED EXCESS CAPACITY (BY CALCULATION) INACTIVE NEGATIVE (BY CALCULATION) CARBONATE CONTENT OF ELECTROLYTE

DPA Analysis/Test Rating Sheet

<u>DPA Analysis/Test Rating Sheet</u>					
<u>Material</u>	<u>Analysis/Test For</u>	<u>Initial</u>	<u>Cell Accept</u>	<u>Down-stream</u>	
Nickel Powder	Bulk Density		N/A	N/A	
	Particle Size				
Sintered Plaque (Unimpregnated)	Weight Nickel per Unit Area				
	Void Fraction (Porosity)				
	Pore Size - Avg and Distributed				
	Sinter Strength				
Positive Plates (New and Used; Dry)	Thickness				
	Weight per Unit Area				
	Residual Void Fraction (Porosity)				
	Total Nickel Active Material				
	Undischarged Nickel Active Material				
	Metallic Nickel in Sinter				
	Cobalt				
	Cadmium				

Material	Analysis/Test For	Initial	Cell Accept	Down - stream
Negative Plates	Electrolyte Content			
(from Activated Cells; Wet)	Flooded Capacity			
Separator (New and Used; Dry)	Thickness			
	Weight per Unit Area			
	Tear Strength			
	Compressibility			
	Wettability by Electrolyte			
	Electrolyte Absorption			
	Electrolyte Distribution between Separator and Plate Materials			
	Resistance to Hydrolysis in Electrolyte			
	Effects of Standing in Electrolyte			
Separator (Used, Wet)	Electrolyte Content			
	Cadmium Compounds Content			

Uniform DPA Committee

DPA Rating Sheet (cont) Pg. 4

<u>Material</u>	<u>Analysis/Test For</u>	<u>Initial</u>	<u>Cell Accept</u>	<u>Down stream</u>
Electrolyte	<u>KOH</u>			
	<u>Carbonate</u>			
	<u>Lithium</u>			
	<u>Copper</u>			
	<u>Silica</u>			
Whole Cell, Activated	In-cell positive and negative capacities; excess negative capacities by the GEP "Electrode Capacity Test" and "CMA".			
	Electrolyte Distribution			

UNIFORM DPA COMMITTEE - REPORT

NON-CONVENTIONAL TEST METHODS

SONIC AND ULTRA-SONIC SCANNING OF PLATE MATERIALS

X-RAY ANALYSIS OF PLATE MATERIALS

ELECTRONIC IMAGE ANALYSIS

PORE SIZE DISTRIBUTION ANALYSIS

OXIDATIVE TESTING OF SEPARATORS

INTERIM RECOMMENDATIONS

1. AT LEAST FOUR DIFFERENT APPLICATIONS OF DPA HAVE BEEN IDENTIFIED, EACH OF WHICH MAY HAVE DIFFERENT REQUIREMENTS FOR DPA:
 - 1.1 FOR NORMAL, QUALITY ASSURANCE DURING THE CELL MANUFACTURING PROCESS, PRIOR TO CELL ACCEPTANCE TESTING.
 - 1.2 FOR END-ITEM CELL ACCEPTANCE, IN CONJUNCTION WITH OR AS A REQUIRED PART OF CELL ACCEPTANCE TESTING.
 - 1.3 FOR "EXTENDED QUALITY VERIFICATION", AFTER SOME SIGNIFICANT AMOUNT OF ADDITIONAL CYCLING, E.G., DURING AND/OR AFTER A 500-CYCLE TEST.
 - 1.4 AS PART OF A CELL FAILURE ANALYSIS.
2. THE "CORE SET" OF ANALYSES/TESTS SHOULD BE THE SAME FOR ALL APPLICATIONS. OPTIONS MAY BE DIFFERENT FOR DIFFERENT APPLICATIONS.
3. DATA SHOULD BE OBTAINED ON EACH LOT OF COMPONENTS DURING CELL MANUFACTURING AND THESE DATA USED AS THE REFERENCE FOR ANY SUBSEQUENT DPA ON A GIVEN LOT OF CELLS. SAMPLES SHOULD BE TAKEN AND STORED FOR POSSIBLE FUTURE USE.

UNIFORM DPA COMMITTEE - REPORT

INTERIM RECOMMENDATIONS (CONTINUED)

4. MEASUREMENT OF TOTAL POSITIVE CAPACITY, PRE-CHARGED NEGATIVE CAPACITY, EXCESS UNCHARGED NEGATIVE CAPACITY, AND INACTIVE NEGATIVE CAPACITY IN ACTIVATED SAMPLE CELLS SHOULD BE PERFORMED AS A PART OF AN INITIAL DPA ON EACH CELL LOT DURING MANUFACTURING. GEP USES A PROPRIETARY INTEGRATED PROCEDURE, REFERRED TO AS THE "ELECTRODE CAPACITY TEST", AND "CHEMICAL ANALYSIS" TO MAKE THESE MEASUREMENTS AND TO REDUCE THE DATA. GEP NORMALLY PERFORMS THIS TEST IMMEDIATELY AFTER SETTING PRECHARGE, AT WHICH POINT THE RESULTS HAVE THEIR GREATEST VALIDITY. THE TEST PROCEDURE, METHOD OF TREATING THE DATA, AND THE INTERPRETATION OF THE DATA AS DONE BY GEP, SHOULD BE UNDERSTOOD BY ALL CELL USERS.
5. ANY DPA DONE ON CELLS AFTER SIGNIFICANT CYCLING SHOULD BE A SUB-SET OF THE INITIAL DPA. HOWEVER, IF ANOMOLOUS BEHAVIOR OR ELECTRICAL FAILURE IS OBSERVED, ADDITIONAL TESTS, TAILORED TO REVEAL THE PROBLEM DETERMINANT, SHOULD BE USED. THE SPECIFICS OF THE LATTER TYPE TESTS ARE CONSIDERED TO BE BEYOND THE SCOPE OF THIS COMMITTEE.

*NICKEL-CADMIUM SEPARATOR
ACCEPTANCE TEST AND CRITERIA
TASK FORCE INVESTIGATION*

1988 NASA/GSFC BATTERY WORKSHOP
NOVEMBER 1-3, 1988

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TASK GROUP MEMBERS

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GATES

NASA LeRC

AEROSPACE

**POWER TECHNOLOGY DIVISION**

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

OBJECTIVE

DEFINE TESTS FOR EVALUATION OF SEPARATORS

ENSURE SEPARATOR QUALITY AND CONSISTENCY

RECOMMEND RANGE FOR SEPARATOR PROPERTIES



AEROSPACE TECHNOLOGY DIRECTORATE

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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA APPROACH

REVIEW GATES TESTS AND PROCEDURES

MAKE RECOMMENDATIONS

TYPE OF TESTS

LEVEL OF TESTING

SEPARATOR PROPERTIES



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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA SEPARATOR ASSESSMENT

Ni-Cd CELLS HAVE BEEN EMPIRICALLY OPTIMIZED FOR PELLON 2505
PELLON 2536 IS NOT A DIRECT REPLACEMENT FOR PELLON 2505
REPLACEMENT SEPARATOR MUST HAVE PROPERTIES AS CLOSE TO THOSE
OF PELLON 2505 AS POSSIBLE
EVALUATION AND ASSESSMENT OF NON-NYLON MATERIALS FOR LONG TERM
REPLACEMENTS MUST BEGIN NOW

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

GENERAL RECOMMENDATIONS

SPECIFICATIONS AND TESTING REQUIRE MORE DETAIL AND DEFINITION
TO ENSURE TRACEABILITY:

- IDENTIFY RELATIVE SAMPLE POSITION ON ROLL
- PERFORM ALL TESTS AT SEPARATOR LOT LEVEL
- IDENTIFY SUBSETS TO PERFORM AT THE ROLL LEVEL
- MEASURE CRITICAL PARAMETERS AT CELL LOT LEVEL

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

GENERAL RECOMMENDATIONS

- INITIATE EXTENSIVE TEST PROGRAM
 - ESTABLISH BASELINE FOR SEPARATOR PROPERTIES
- PERIODICALLY EVALUATE AND REVIEW TEST PROGRAM
 - TYPE OF TESTS
 - LEVELS AT WHICH TESTS ARE PERFORMED
 - REQUIRED SEPARATOR PROPERTIES
- UPGRADE SEPARATOR TEST PROCEDURES
 - ADD TESTS AS REQUIRED
 - ELIMINATE UNNECESSARY TESTS
 - MODIFY TEST PROCEDURES

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

AEROSPACE SEPARATOR ACCEPTANCE TESTS

CHEMICAL ANALYSIS

EXTRACTABLE ORGANICS
INORGANICS

ELECTROLYTE RETENTION

AIR PERMEABILITY

SEM ANALYSIS

WEIGHT TEST
FOAM TEST

RESISTANCE TO ELECTROLYTE
WEIGHT LOSS AND SHRINKAGE
REDUCED STRENGTH

THICKNESS

CHEMICAL OXIDATION

THICKNESS VARIATION

DISCOLORATION

TENSILE STRENGTH/ELONGATION
WITH MACHINE DIRECTION
ACROSS MACHINE DIRECTION

FOREIGN PARTICLE COUNT

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: EXTRACTABLE ORGANICS

PURPOSE: EVALUATE SEPARATOR FOR PRESENCE OF ORGANICS THAT
 MIGHT ADVERSELY EFFECT CELL PERFORMANCE OR
 SEPARATOR STRUCTURAL INTEGRITY

CRITERIA: LESS THAN 2%

RECOMMENDATION:

IDENTIFY POSSIBLE CONTAMINANTS
DETERMINE POSSIBLE EFFECTS ON CELL PERFORMANCE
SET LIMITS FOR INDIVIDUAL COMPONENTS

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: SEM ANALYSIS

PURPOSE: VISUAL ANALYSIS OF SAMPLES FOR UNIFORMITY

CRITERIA:

RECOMMENDATION:

SET UP A GO - NO-GO CRITERION FOR THIS TEST

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: WEIGHT TEST

PURPOSE: DETERMINE LEVEL OF LEACHABLES, VOLATILES, AND
WEIGHT LOSS

CRITERIA: VOLATILES:
WATER LEACHABLES: <1%
TOTAL % WEIGHT LOSS:

RECOMMENDATION:

IDENTIFY WHAT CONTAMINANTS MAY BE PRESENT AND
IDENTIFY POTENTIAL EFFECTS ON CELL

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: THICKNESS, THICKNESS VARIATION

PURPOSE: DETERMINE SEPARATOR THICKNESS AND UNIFORMITY

CRITERIA: MATERIAL, CELL DEPENDANT

RECOMMENDATION:

STANDARDIZE PROCEDURES FOR MEASURING THICKNESS
EVALUATE THICKNESS VS APPLIED PRESSURE

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: TENSILE STRENGTH – WITH MACHINE DIRECTION
ACROSS MACHINE DIRECTION

PURPOSE: DETERMINE MATERIAL STRENGTH FOR MACHINE PROCESSING
BASELINE TO COMPARE STRENGTH FOLLOWING EXPOSURE
TO ELECTROLYTE (REDUCED STRENGTH TEST)

CRITERIA: MINIMUM PROCESSING REQUIREMENT

RECOMMENDATION:

DETERMINE REQUIRED STRENGTH FOR INDIVIDUAL MATERIALS
SPECIFY MINIMUM REQUIRED STRENGTH



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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: ELECTROLYTE RETENTION

PURPOSE: EVALUATE SEPARATOR ELECTROLYTE RETENTION CAPABILITIES

CRITERIA: % BASED ON WEIGHT, MATERIAL SPECIFIC

RECOMMENDATION:

**EVALUATE RETENTION UNDER COMPRESSION
EXPRESS RETENTION AS (GRAMS KOH)/AREA**

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: AIR PERMEABILITY

PURPOSE: COMMERCIAL REQUIREMENT
EVALUATE GAS TRANSPORT
MEASURE OF UNIFORMITY

CRITERIA:

RECOMMENDATION:
EVALUATE BUBBLE PRESSURE AS A MORE REPRESENTATIVE
MEASURE OF GAS TRANSPORT

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: OXIDIZABLE MATERIALS, AgO

PURPOSE: EVALUATE SEPARATOR FOR PRESENCE OF OXIDIZABLE MATERIAL
TEST FOR TREATMENT OR CONTAMINATION

CRITERIA: DISCOLORATION INDICATES TREATMENT OR CONTAMINATION

RECOMMENDATION:
SPECIFY SOLUTION AND TEMPERATURE

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: WETTABILITY

PURPOSE: EVALUATE SEPARATOR FOR PRESENCE OF CONTAMINANTS

CRITERIA: >5 MINUTES REQUIRED FOR WETTING

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: CAPILLARITY

PURPOSE: MEASUREMENT OF WICKING AS TEST FOR CONTAMINATION

CRITERIA:



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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: RESISTANCE TO ELECTROLYTE

PURPOSE: MEASUREMENT OF SUSCEPTIBILITY TO HYDROLYSIS

CRITERIA: DETERMINE NOMINAL ACCEPTABLE LEVELS

RECOMMENDATION:

EXPOSURE TO 70 DEG KOH MUST BE DONE WITHOUT
EXPOSURE TO AIR FOR REPRODUCIBILITY
FOLLOWING EXPOSURE RINSE SAMPLE WITH FRESH WARM
KOH TO LEACH REACTION PRODUCTS



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NICKEL--CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: REDUCED STRENGTH

PURPOSE: EVALUATE DETERIORATION FROM EXPOSURE TO KOH

CRITERIA: DIFFERENCES IN TENSILE STRENGTH FROM NEW MATERIAL

RECOMMENDATION:

EXPOSURE TO 70 DEG KOH MUST BE DONE WITHOUT
EXPOSURE TO AIR FOR REPRODUCIBILITY
FOLLOWING EXPOSURE RINSE SAMPLE WITH FRESH WARM
KOH TO LEACH REACTION PRODUCTS

**POWER TECHNOLOGY DIVISION****NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA**

TEST: CHEMICAL OXIDATION, KMnO_4

PURPOSE: EVALUATE WEIGHT LOSS RESULTING FROM CHEMICAL OXIDATION

CRITERIA: DETERMINE ALLOWABLE MAXIMUM

RECOMMENDATION:

FREUDENBERG TEST
AEROSPACE IN CELL TEST MAY BE BETTER MEASURE



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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

TEST: DISCOLORATION, FOREIGN PARTICLES

PURPOSE: VISUAL OBSERVATIONS OF SEPARATOR QUALITY

CRITERIA: DETERMINE GO — NO—GO CRITERION



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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

ADDITIONAL TESTS RECOMMENDED

OXIDATION RESISTANCE
IN CELL ENVIRONMENT
AEROSPACE PROCEDURE

RESISTIVITY IN ELECTROLYTE
COMPRESSED TO PREDETERMINED LEVEL
UNCOMPRESSED

POROSITY, PORE SIZE DISTRIBUTION
BUBBLE PRESSURE

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

ADDITIONAL TESTS RECOMMENDED

OXIDATION RESISTANCE
IN CELL ENVIRONMENT
AEROSPACE PROCEDURE

RESISTIVITY IN ELECTROLYTE
COMPRESSED TO PREDETERMINED LEVEL
UNCOMPRESSED

POROSITY, PORE SIZE DISTRIBUTION
BUBBLE PRESSURE

NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA AEROSPACE SEPARATOR ACCEPTANCE TESTS RECOMMENDED TEST LEVELS

TEST	SEPARATOR LOT	ROLL	CELL LOT
CHEMICAL ANALYSIS			
EXTRACTABLE ORGANICS	✓		
INORGANICS	✓		
SEM ANALYSIS	✓		
WEIGHT TEST	✓	✓	
FOAM TEST	✓	✓	✓
THICKNESS	✓	✓	
THICKNESS VARIATION			✓
TENSILE STRENGTH			
WITH MACHINE DIRECTION	✓		
ACROSS MACHINE DIRECTION	✓		
ELECTROLYTE RETENTION	✓	✓	
AIR PERMEABILITY	✓	✓	



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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA
AEROSPACE SEPARATOR ACCEPTANCE TESTS
RECOMMENDED TEST LEVELS

TEST	SEPARATOR LOT	ROLL	CELL LOT
OXIDIZABLE MATERIALS, Ago	✓	✓	
WETTABILITY	✓	✓	
CAPILLARITY	✓	✓	
RESISTANCE TO ELECTROLYTE WEIGHT LOSS AND SHRINKAGE REDUCED STRENGTH	BY REQUEST		
CHEMICAL OXIDATION	"		
FOREIGN PARTICLE COUNT	"	✓	
DISCOLORATION		✓	
OXIDATION RESISTANCE	✓		✓
ELECTRICAL RESISTANCE	✓		
POROSITY, PORE SIZE	✓		
BUBBLE PRESSURE	✓		



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NICKEL-CADMIUM SEPARATOR ACCEPTANCE TEST AND CRITERIA

SUMMARY

SEPARATOR ACCEPTANCE TESTS REVIEWED

INITIATE EVALUATION PROCESS

REPLACEMENT MATERIALS REQUIRE EXTENSIVE STUDY

IDENTIFY KEY PROPERTIES AND MEASUREMENT REQUIREMENTS

TASK GROUP PRESENTATION:

4. PLATE ISSUES TASK TEAM

(NOT SUBMITTED)

DEAN MAURER, AT&T BELL LABS

NASA TASK FORCE -- FUTURE Ni-Cd CELL DESIGN

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OBJECTIVE

RECOMMEND PROMISING APPROACHES FOR DEVELOPMENT OF
ADVANCED NI-CD CELL TECHNOLOGY.

LEO

10 YEARS, 30% DOD
7 YEARS, 35% DOD

GEO

20 YEARS, 60% DOD
15 YEARS, 75% DOD

CELL SIZE:

- 1) SAME AS STANDARD 50 AH CELL
- 2) NEW SIZE CELL

RECOMMENDATIONS

MANUFACTURING FACILITY

SEPARATOR

NICKEL POSITIVE ELECTRODES

CADMIUM NEGATIVE ELECTRODES

MANUFACTURING FACILITY

COMPLETE CONTROL, INCOMING MATERIALS TO FINISHED CELLS

- 0 ALL STEPS**
- 0 ALL MATERIALS AND PROCESSES**
- 0 MAJOR IMPROVEMENTS OVER PRESENT CONTROLS**

SEPARATOR

NYLON DISALLOWED

USE SEPARATOR DEMONSTRATED TO BE EXCELLENT FOR Ni-Cd

- 0 WETTABILITY
- 0 ELECTROLYTE RETENTION
- 0 HANDLABILITY
- 0 SUITABLE DENSITY
- 0 SUITABLE POROSITY
- 0 ADDITIVE-FREE

MAIN CANDIDATES

- 0 ZIRCAR + PBI
- 0 ZIRCAR + POLYSULFONE
- 0 POLYPROPYLENE-BASED + PBI
- 0 ADVANCED POLYPROPYLENE-BASED

NICKEL SINTER FOR NICKEL ELECTRODE

SLURRY OR DRY POWDER

- 0 MEAN PORE SIZE 12-13 MICRONS
- 0 < 5% GREATER THAN 50 MICRONS
- 0 < 5% LESS THAN 3 MICRONS
- 0 SINTER POROSITY 87-90%
- 0 SUBSTRATE - OPEN
- 0 3 POINT BEND TEST, 550 +/- 50 PSI
- 0 NO COMPRESSION OR SIZING, COINING ONLY
- 0 AQUEOUS IMPREGNATION:
 - 0 PASSIVATION REQUIRED
 - 0 TIME AND TEMPERATURE CONTROLS REQUIRED
 - 0 MUST PASS CORROSION TEST, 15 MIN AT 325oF,
Cd(NO3)2 BATH, MEET MIN AND MAX REQUIREMENTS

NICKEL ELECTRODE

ELECTROCHEMICAL IMPREGNATION, AQUEOUS OR ALCOHOLIC METHOD

- o LOADING RANGE 1.7 +/- 0.1 g/cc VOID
- o LOADING CONTROL +/- 0.05 g/cc VOID
- o Co(OH)_2 -- 7 TO 10%, CONTROLLED TO +/- 1%
- o NO SIZING
- o FORMATION
 - o 60°C
 - o 5C CHARGE AND DISCHARGE
 - o 120% OVERCHARGE
- o UTILIZATION
 - o FLOODED CAPACITY
 - o 100% BASED ON THEORETICAL LOADING
 - o C/5 CHARGE, C/2 DISCHARGE
- o STRESS TEST
 - o 25°C
 - o 10C RATE CHARGE/DISCHARGE
 - o 100% OVERCHARGE, 100% OVERDISCHARGE
 - o 200 CYCLES
 - o NO MORE THAN 1% SWELLING
 - o NO MORE THAN 3.5% BLEMISHES
 - o NO LOSS IN CAPACITY COMPARED WITH FIRST CYCLE
WITH C/5 CHARGE TO 120%, C/2 DISCHARGE
TO 1.0 V, 25°C

NICKEL SINTER FOR CADMIUM ELECTRODE

SLURRY OR DRY POWDER

- 0 THICKNESS 30 MILS MAX (28-30 MILS TYPICAL)
- 0 PORE SIZE DISTRIBUTION SIMILAR TO NI ELECTRODE
- 0 MAX C RATE CURRENT DENSITY: 5 MA/CM² PER INTERFACE
- 0 SUBSTRATE: OPEN
- 0 NO COMPRESSION OR SIZING
- 0 PASSIVATION REQUIRED
 - 0 MUST PASS CORROSION TEST, SAME AS FOR NI

CADMIUM ELECTRODE

ELECTROCHEMICAL IMPREGNATION

- 0 LOAD 1.8-1.9 GRAMS $\text{Cd}(\text{OH})_2$ PER CC VOID, CONTROL TO 0.08
- 0 NO COMPRESSION, NO SIZING
- 0 FORMATION: SAME AS NI ELECTRODE
- 0 UTILIZATION
 - 0 80% USING C/5 CHARGE AND DISCHARGE
 - 0 DISCHARGE TO 0.0 V VS Hg/HgO
- 0 STRESS TEST REQUIRED (TBD)

MISCELLANEOUS

- 0 CAPACITY -- 50 AH NOMINAL
- 0 NEGATIVE/POSITIVE RATIO -- 2.0 ON THEORETICAL BASIS
- 0 DIMENSIONS
 - 0 NI ELECTRODE THICKNESS DERIVED FROM ABOVE DATA
 - 0 INTERELECTRODE SPACING -- 9 TO 11 MILS
 - 0 CASE WALL -- 19 MILS
- 0 ELECTROLYTE FILL
 - 0 VOLUME BASIS WITH PRESSURE ADJUSTMENT
 - 0 31% KOH
 - 0 NO Li(OH)
- 0 CELL SEAL -- EITHER CERAMIC, ZEIGLER, OR STADNICK SEAL
- 0 CORE WRAP
 - 0 IF POLYPROPYLENE IS USE, BAG NI ELECTRODES
 - 0 IF ZIRCAR/PBI IS USED:
 - 0 MUST BE IN SHEET FORM
 - 0 SHOULD HAVE 5 MIL POLYPROPYLENE LINER
 - 0 SHOULD EXTEND TO BOTTOM OF CAN

TASK GROUP 6 CHARTER

TASK 1: Scoping Tasks for Evaluation of NWSC Data

TASK 2: Recommendations on Near-Term Actions for Ni-Cd Cell Design

As I understand from Dr. Jerry Halpert's letter and subsequent discussions with and the other task force leaders, our present job assignment is to scope out the work we think needs to be done. We are not expected to actually do the work now!

We are to do the following:

- A. Define the objectives.
- B. Itemize specific operations to be done.
- C. Identify specific steps or techniques to be used.
Also point out steps or techniques that require additional study.
- D. Prioritize the steps, and list the minimum required to achieve the task force objectives.

TASK FORCE GROUP 6 - EVALUATION OF NWSC

DATA, AND RECOMMENDATION OF NEAR-TERM DESIGN FIXES

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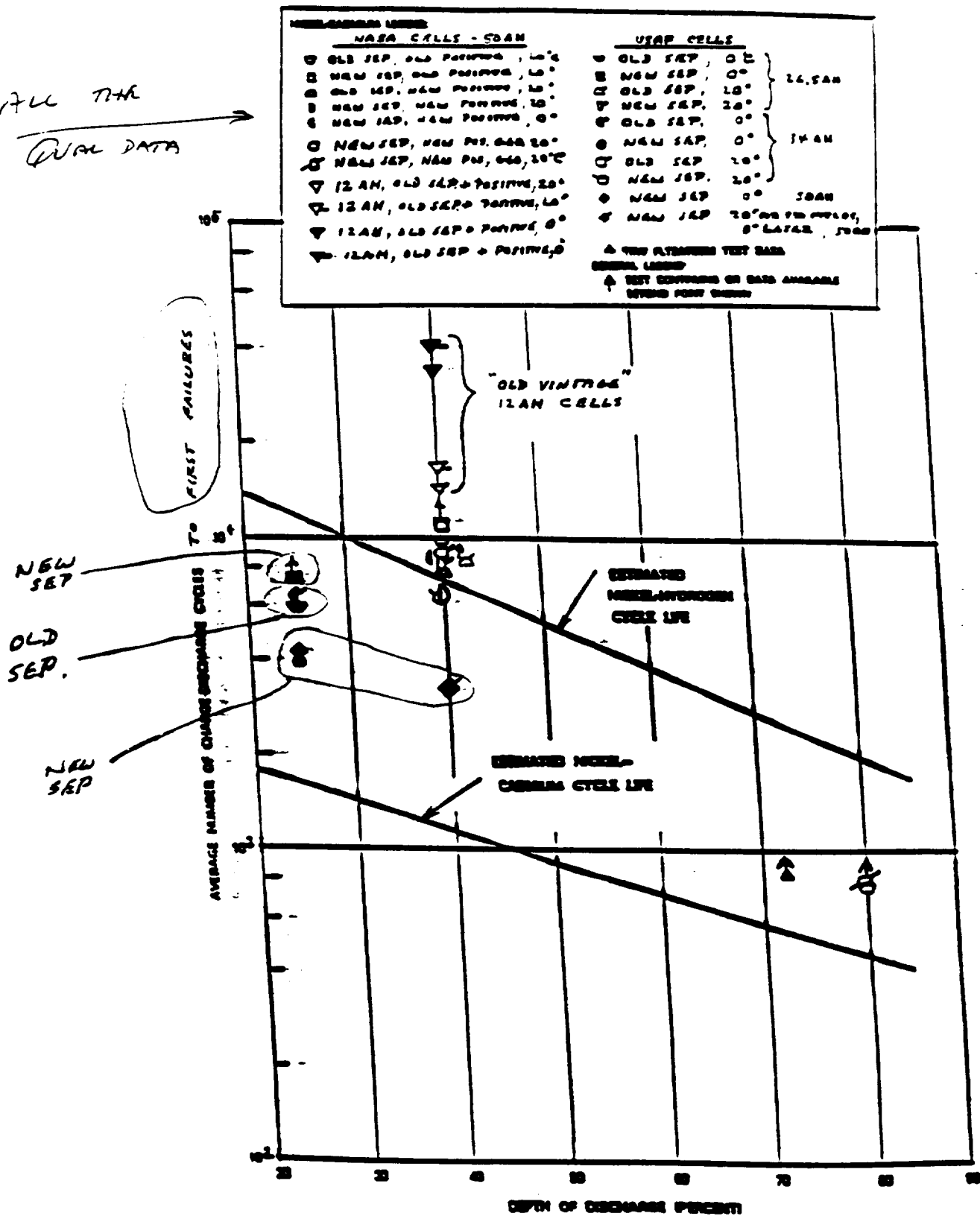
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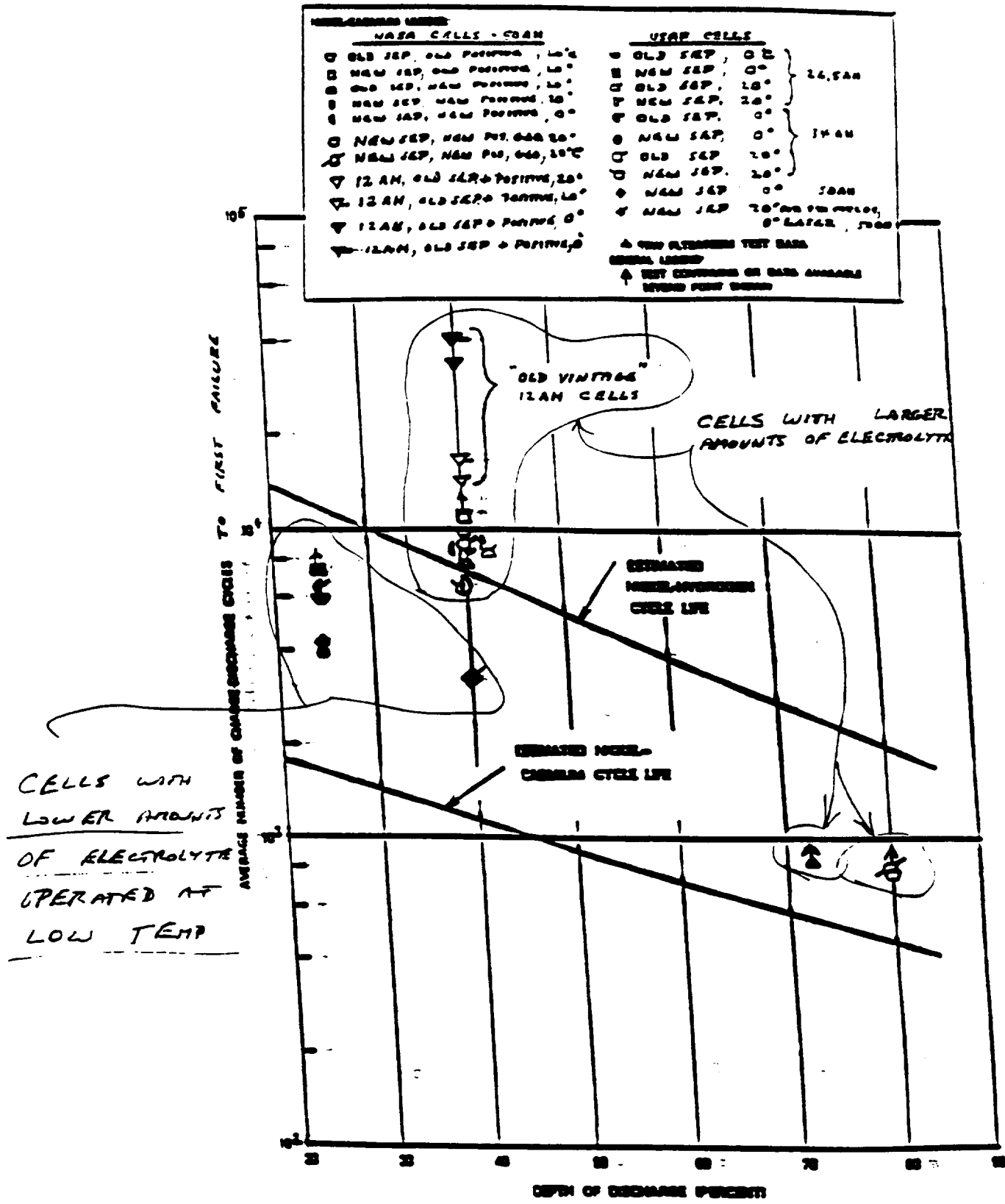
(213) 336-7055

ALL THE
QUAL DATA



Nickel-cadmium Battery Cell Life

NOTE: LOW TEMPERATURE POINTS DASHED



Nickel-cadmium Battery Cell Life
 NOTE: LOW TEMPERATURE POINTS DRAWN

CONCLUSIONS FROM CYCLE PLOTS

- 0 FIRST FAILURES DO NOT CORRELATE WELL WITH TYPE OF SEPARATOR OR TYPE OF POSITIVE PLATES
- 0 EARLIEST FAILURES WERE ON CELLS WITH LOW ELECTROLYTE FILL. THAT WERE CYCLED AT 0°C. CELLS TESTED AT HIGHER TEMPERATURE LASTED LONGER.
- 0 NI-Cd CELLS WITH NEW COMPONENTS ARE NOT PERFORMING AS WELL AS THE BEST "VINTAGE" NI-Cd CELLS (ABOUT 1/4 OR 1/2 THE NUMBER OF CYCLES)
- 0 ALL CELLS WITH SUFFICIENT ELECTROLYTE AND EITHER OLD OR NEW COMPONENTS PERFORMED EXCELLENTLY IN CYCLING TESTS:
- 0 ALL CELLS IN THE QUAL TESTS APPEAR TO EXCEED THE NI-Cd ESTIMATED LIFE CURVE BY A WIDE MARGIN:

ELECTROLYTE QUANTITY IN NASA QUAL TEST CELLS

Pack and cell no.	sep type	Cap to 0v	ml of KOH	KOH/AH	Burns, Cd at top of cell
150A/50AB20/L13-5	2505	67.12	166	2.47	no
150A/50AB20/L13-16	2505	68.47	166	2.42	no
150A/50AB20/L13-20	2505	72.67	166	2.28	no
REF/50AB20/L13-13	2505	71.22	166	2.33	no, uncycled
150B/50AB25/L1-6	2536	71.91	155	2.16	no
150H/50AB25/L1-11	2536	72.65	160	2.20	no
150C/50AB26/L1-7	2505	68.32	162	2.37	no
REF/50AB26/L1-1	2505	68.59	162	2.36	no, uncycled
150D/50AB27/L1-4	2536	65.99	155	2.34	no
150I/50AB27/L1-7	2536	69.36	155	2.23	no
150G/50AB27/L1-16	2536	69.08	155	2.24	no

				2.30	ave.

ELECTROLYTE QUANTITY IN QUAL TEST CELLS FOR AEROSPACE CORP

Pack and cell no.	sep type	Cap to 0v	ml of KOH	KOH/AH	Burns, Cd at top of cell
326A/30AB10/L16-109	2505	38.71	81.0	2.13	yes
REF/30AB10/L16-112	2505	38.46	81.0	2.11	no, uncycled
510/35AB02/L13-11	2505	45.37	85.0	1.87	no, uncycled
510/35AB13/L1-23	2536	45.50	82.0	1.80	no, uncycled
REF/35AB02/L13-19	2505	42.76	85.0	1.99	no, uncycled
334D/34AB03/L1-27	2536	49.16	100.0	2.03	yes
334B/34AB03/L1-32	2536	50.91	100.0	1.96	yes
REF/34AB02/L3-18	2505	48.91	102.0	2.08	no, uncycled
350D/50AB28/L1-33	2536	65.94	120.0	1.82	yes
350B/50AB28/L1-35	2536	64.64	120.0	1.86	yes
350D/50AB28/L1-23	2536	not measured	120.0	N/A	yes, shorted
REF/50AB24/L8-19	2505	63.03	124.5	1.97	no, uncycled

					1.96 ave.

SUMMARY OF INFORMATION ON ELECTROLYTE QUANTITY

ABSTRACTED FROM DPA ANALYSES

- 0 NEW #2536 SEPARATOR ACCEPTS LESS KOH THAN OLD #2505 MATERIAL
 - EX. 84 VS 87ML IN RCA 26.5AH CELLS
- 0 NO SEPARATOR PINHOLE OR BURN SPOTS REPORTED IN DPA'S OF NASA CELLS, ALTHOUGH THERE HAD BEEN EVIDENCE OF SOFT SHORTS IN A FEW VOLTAGE PROFILES
- 0 PINHOLES, BURNS, AND CD MIGRATION IN A BAND AT THE TOP OF THE PLATES OBSERVED IN DPA'S OF ALL CYCLED CELLS MADE FOR AEROSPACE CORP.
- 0 ALL NASA CELLS CONTAIN MORE ELECTROLYTE THAN CELLS MADE FOR AEROSPACE CORP - 2.30 VS 1.96 ML/AH
- 0 THIS SYSTEMATIC DIFFERENCE OF 15% MAY EXPLAIN THE EARLY DRYOUT AT THE TOP OF THE CELLS TESTED FOR AEROSPACE CORP.

ANALYSIS OF NI-Cd TEST DATA

PRELIMINARY CONCLUSIONS

- 0 NO INFANT MORTALITY FAILURES IN QUAL DATA, ALTHOUGH SOME CELLS FAILED ACCEPTANCE TESTS AND WERE REJECTED DUE TO HIGH VOLTAGE ON CHARGE.
- 0 FIRST FAILURES DO NOT CORRELATE WELL WITH TYPE OF SEPARATOR OR TYPE OF POSITIVE PLATE
- 0 EARLIEST FAILURES OCCURED ON CELLS WITH LOW ELECTROLYTE FILL, RUN AT LOW TEMPERATURE (00C). WHILE CELLS TESTED AT HIGHER TEMP (200C) LASTED LONGER.
- 0 OVERALL RATE OF CADMIUM BUILDUP IS ABOUT 50% LOWER IN NEW #2536 SEPARATOR
- 0 COMPLETE PACK FAILURES (80 TO 100% FAIL) OCCURED ONLY WITH CELLS HAVING NEW 2536 SEPARATOR IN COMBINATION WITH LOW ELECTROLYTE FILL. (1.8 TO 1.9 ML / ALL)
- 0 ALL CYCLED CELLS WITH LOW ELECTROLYTE FILL THAT WERE ANALYZED BY DPA HAD CD BAND AND PINHOLES OR BURNS AT TOP OF THE PLATES - PERFECT CORRELATION
- 0 CELLS WITH SUFFICIENT ELECTROLYTE AND EITHER OLD OR NEW TYPE COMPONENTS PERFORMED EXCELLENTLY IN CYCLING TESTS.
- 0 SOME PACKS LOST ONE CELL. AND MOST PACKS IN THE TEST ARE CONTINUING TO CYCLE
- 0 NI-Cd CELLS WITH NEW COMPONENTS ARE NOT PERFORMING AS WELL AS THE BEST "VINTAGE" NI-Cd CELLS (ABOUT 1/3 OR 1/2 THE NUMBER OF CYCLES)
- 0 ALL CELLS IN QUAL TESTS APPEAR TO MEET OR EXCEED THE NI-Cd ESTIMATED CYCLE LIFE CURVE.

OUTLINE - TASKS FOR EVALUATION OF DATA FROM Ni-Cd
SEPARATOR QUALIFICATION TESTS AT NWSC - 21 September 1988

Task A. Update and improve the data base.

1. Update the data summaries - Latest NWSC cycle data
 - Gates DPA data
 - Gates separator lot analysis, electrode lot analysis, and ATP data
2. Collect data on key design features of each of the cells-Ag or teflonated negative, positive loading, quantity of cobalt and cadmium in the positive, gas passivation, electrolyte quantity, lightweight or low profile can, etc.*
3. Enhance the data base - Clearly identify changes made in conditions during cycling period. Also obtain individual cell voltage plots just prior to failure, and/or just prior to pulling cell for DPA.
4. Publish the data base - compile the summaries of key characteristics, cyclic test results, and related DPA analyses in report form.
5. Flag any data that is questionable or invalid due to testing difficulties.

Task B. Analyze the data in more detail.

1. Plot up the updated cycle data obtained in this set of tests in a summary plot vs. DOD.
2. Compare the overall cyclic performance obtained in Crane tests of good Ni-Cd cells. Show averages and variability in the summary plot.
3. Pinpoint the cells in this test which became negative limited, by reference to voltage-time plots and DPA data.

*NOTE: Include plaque sintering time and temperature, type of powder, electrolyte quantity, etc.

Task B (con't).

4. Try to understand why these cells became negative limited. Check precharge. Examine the specific lot history of separator used. Did it degrade more rapidly than normal?
5. Pinpoint the cells that had soft or hard shorts, by reference to voltage-time plots and DPA data.
6. Try to understand why these cells went short. Evaluate electrolyte quantity. Examine their specific reconditioning history. Is more reconditioning recommended to avoid soft shorts? Were negatives teflonated? Cadmium migration patterns? Any other metal in the separator? Did they fail by separator dryout?

Task C. Summarize and publish the key results of the data analyses in report form.

1. If any "dry stored" old lot cells of the same P.N. are available, should they be filled, and added as control samples? Also, recommend specific new samples for inclusion in NWSC tests, if needed.
2. Consider whether there are any major holes in the data which could benefit from the addition of new test regimes or new test samples.
3. Include "lessons learned" and recommendations resulting from them regarding the planning and execution of future tests.

OUTLINE - TASK OF RECOMMENDING NEAR-TERM

ACTIONS FOR Ni-Cd CELLS

Task A. Map out logical courses of action based on a careful analysis of the NWSC cyclic performance data, as described in the data evaluation task.

Task B. Define alternatives. Some possibilities might include:

- One solution would be to "peel-back" as many of the design changes as possible made over the last 5 years. The intent is to go back to a design which all customers were very satisfied with in regard to its long term performance. Hopefully that leaves only one change - the separator material. Then either the use of acceptable stored Pellon 2505 or acceptable 2536, provided it can accommodate a minimum electrolyte quantity of 3 cc/rated A.H. in a finished cell (the old established rule), is suggested.
- Freeze the design for the short term until more research is done. NASA std. cell performance with 2536 Pellon separator appears acceptable for GEO and for some LEO applications.
- Continue production with 2536 separator; adding tests for separator oxidation, and ensuring that electrolyte quantity exceeds some specified value.
- Continue production; improve QA based on recommendations from QA task group, and adding tests for separator oxidation, ensuring that electrolyte quantity exceeds some specified value. Also perform extended DPA analysis on one cell from each lot, incorporating recommendations of DPA task group.
- Suggest more extensive cell design changes based on results of additional analysis of qual tests.

Task C. Recommend a short-term course of action for Ni-Cd cells from the above alternatives. Provide rationale demonstrating that this appears to be supported by analysis of all the existing NWSC and other pertinent data.

APPENDIX A
NASA AND USAF NI-Cd
SEPARATOR QUALIFICATION
SUMMARIES OF CYCLE AND DPA DATA

TABLE 1: SUMMARY OF NASA LEO TEST

Type Cell	# Cells	DOD %	Temp °C	FIRST OCCURRENCE OF Problem cells		TOTAL NUMBER OF Failed cells		Total Cycles	PACK #
				#	Cycle	#	Cycle		
Std 50 Ah, old sep, old positive elec	5	40	20	2	9978	1	10627	>10627	150A
Std 50 Ah, new sep, old positive elec	5	40	20	0	-	0	-	>10748	150B
Std 50 Ah, old sep, new positive elec	5	40	20	3	7143	2	7143	>9755	150C
Std 50 Ah, new sep, new positive elec	5	40	20	1	6563	1	6882	>10622	150D
Std 50 Ah, new sep, new positive elec	5	40	0	1	2833	1	8047	>8047	150G
GEO TEST { Std 50 Ah, new sep, old positive elec Std 50 Ah, new sep, new positive elec	5	80	20	ALL	560	0	-	?	150H
	5	80	20	ALL	560	0	-	?	150I
	5	80	20	ALL	560	0	-	?	150I
Old Vintage									
12 Ah, old sep & pos	4	40	20	?	?	2	14517	17759	3E
12 Ah, old sep & pos	4	40	20	?	?	0	-	17781	3F
20 Ah, old sep & pos	4	40	0	?	?	2	34369	40300	1H
20 Ah, old sep & pos	4	40	0	?	?	0	-	40137	1J

TABLE 3: SUMMARY OF AIR FORCE/NAVY LEO TEST

Type cell	% DOD		Temp °C	FIRST OCCURRENCE OF Problem cells		TOTAL NUMBER OF Failed cells		PACK NUMBER
	# Cells	# Cycle		# Cycle	Total Cycles			
26.5 Ah, old sep	5	25	0	1	3576	1	7978	326A
26.5 Ah, new sep	5	25	0	0	-	0	-	326B
26.5 Ah, old sep	9	40	20	1	5929	0	-	326C
26.5 Ah, new sep	9	40	20	1	7197	0	-	326D
34 Ah, old sep	5	25	0	1	5991	1	6241	334A
34 Ah, new sep	5	25	0	4	1583	4	4012	334B
34 Ah, old sep	10	40	20	0	-	0	-	334C
34 Ah, new sep	10	40	20	5	6009	4	6095	334D
LW 50 Ah, new sep	5	25	0	5	4210	4	4502	350B
LW 50 Ah, new sep	10	40	20,0	10	2592	10	3260	350D

DTA SUMMARY - NASA CELLS

CRANE JOB 512--ANALYSIS RESULTS SUMMARY												
(DATA IN AH)												
04/18/88	150A	150A	150A	REF	150B	150H	150C	REF	150D	GEO	LEO	
ITEM	50AB20	50AB20	50AB20	50AB20	50AB25	50AB25	50AB26	50AB26	50AB27	50AB27	50AB27	
==BASELINE	L13-5	L13-16	L13-20	L13-13*	L1-6	L1-11	L1-7	L1-1*	L1-4	L1-7	L1-16	
PLATE TYPE	NON-P	NON-P	NON-P	NON-P	NON-P	NON-P	PASS	PASS	PASS	PASS	PASS	
SEP TYPE	2505	2505	2505	2505	2536	2536	2505	2505	2536	2536	2536	
SEP LOT	30158	30158	30158	30158	T62152	T62152	30158	30158	T62152	T62152	T62152	
ROLL #	1LR037	1LR037	1LR037	1LR037			5LR037	5LR037				
POS 0.5V	58.33	58.95	59.88	59.23	61.73	63.52	59.67	60.62	55.03	58.58	58.73	
POS 0.0V	67.12	68.47	72.67	71.22	71.91	72.65	68.32	68.59	65.99	69.36	69.08	
DELTA POV	-4.10	-2.75	1.45	0.00	0.69	1.43	-0.27	0.00	-2.60	0.77	0.49	CHANGE & POSITIVE CAPAC
CHEN POS	88.06	87.15	87.37	78.50	82.59	83.05	78.95	74.86	77.36	78.95	84.87	
CHG NEG-02	28.45	24.61	20.98	13.74	25.80	25.00	25.07	15.55	24.80	22.54	30.40	
CHG RESID	10.41	12.03	12.84	3.55	11.10	5.78	17.00	5.28	18.74	14.23	4.74	
TOT PCG	38.86	36.64	33.82	17.29	36.90	30.78	42.07	20.83	43.54	36.77	35.14	
DELTA TOTPCG	21.57	19.35	16.53	0.00	19.61	13.49	21.24	0.00	22.71	15.94	14.31	
TOT CHG NEG	105.98	105.11	106.49	88.51	108.81	103.43	110.39	89.42	109.53	106.13	104.22	
DELTA TCH	17.47	16.60	17.98	0.00	20.30	14.92	20.97	0.00	20.11	16.71	14.80	
CHEN NEG	104.44	105.65	109.76	134.42	115.80	125.23	108.55	130.06	116.53	118.22	128.37	
RESIDUE-GH	1.778	2.436	1.563	0.039	1.375	5.498	4.742	0.124	1.446	1.824	0.118	
SEP-Cd2-GH	25.100	29.439	30.354	0.081	16.153	0.357	13.495	0.145	13.417	8.05	0.560	
POS APH-AH	13.82	13.48	13.40	7.79	14.65	11.72	14.40	8.62	14.65	13.31	12.22	
APH DELTA-AH	5.03	5.69	5.61	0.00	6.86	3.93	5.78	0.00	6.03	4.69	3.60	
TCT CHN	121.10	123.07	127.12	134.46	129.11	131.31	121.04	130.16	128.03	126.54	132.22	
DELTA CHN	-13.37	-11.39	-7.35	0.00	-5.35	-3.15	-9.12	0.00	-2.13	-3.62	2.06	
NA-AVN	15.12	17.96	20.63	45.95	20.30	27.88	10.65	40.74	18.50	20.41	28.00	
DELTA NA-AVN	-30.84	-27.99	-25.33	0.00	-25.65	-18.07	-30.09	0.00	-22.24	-20.33	-12.74	
AVAIL NEG	4.08	6.93	9.59	34.92	9.27	16.85	3.70	33.79	11.55	13.46	21.05	
DELTA AVN	-30.84	-27.99	-25.33	0.00	-25.65	-18.07	-30.09	0.00	-22.24	-20.33	-12.74	
POS THK(NIL)	32.2	32.5	32.1	29.1	31.4	30.4	29.8	28.1	29.5	29.5	29.1	
NON SPEC	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	LOS. IF O.C PROT
NEG THK(NIL)	32.6	33.7	32.6	32.6	32.0	32.3	32.9	33.0	34.9	34.2	32.8	
NON SPEC	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	
KOH QTY (ML)	166.0	166.0	166.0	166.0	155.0	160.0	162.0	162.0	155.0	155.0	155.0	
K2CO3 %	6.38	6.16	6.21	4.84	5.60	7.08	8.33	5.92	7.02	6.40	6.56	

DPA SUMMARY - USAF CELLS

04/14/88 CRANE JOB 513--ANALYSIS RESULTS SUMMARY													
ITEM	326A	REF	STO	STO	(DATA IN AN)	314B	334B	REF	350D	350B	350A	REF	
326A	30AB10	30AB10	35AB02	35AB13	35AB02	34AB03	34AB03	34AB02	30AB28	30AB28	30AB28	30AB24	
326A	L16-109	L16-112	L13-11	L1-23	L13-19	L1-27	L1-32	L1-18	L1-33	L1-35	L1-23	L1-19	
SEP TYPE	2505	2505	2505	2536	2505	2536	2536	2505	2536	2536	2536	2505	
SEP LOT	51562-52	51562-52	30158	T62152	30158	T62152	T62152	30158	T62152	T62152	T62152	51562-28	
			RL326460	RL326460				3LR037					
POS 0.5V	29.82	33.18	40.26	40.09	35.65	41.71	44.30	43.57	57.11	54.18	N/A	56.27	
POS 0.0V	38.71	38.46	45.37	45.50	42.76	49.16	50.91	48.91	65.94	64.64	N/A	63.03	
DELTA POV	0.25	0.00	2.61	2.74	0.00	0.25	2.00	0.00	2.91	1.61	N/A	0.00	
CHG NEG-02	11.18	5.33	16.05	14.14	8.18	21.31	18.38	11.49	20.79	16.12		11.13	
CHG RESID	3.90	4.87	2.11	2.73	2.38	4.48	4.4	2.34	5.52	7.39	4.53	2.20	
TOT PCG	15.08	10.20	18.16	16.87	10.56	25.79	22.78	13.83	26.31	23.51		13.33	
DELTA TOTPCG	4.88	0.00	7.60	6.31	0.00	11.96	8.95	0.00	12.98	10.18		0.00	
TOT CHG NEG	53.79	48.66	63.53	62.37	53.32	74.95	73.69	62.74	92.25	88.15		76.36	
DELTA TCH	5.13	0.00	10.21	9.05	0.00	12.21	10.95	0.00	15.89	11.79		0.00	
CHN NEG	69.81	75.20	73.71	74.28	77.85	82.19	85.32	92.99	105.80	102.26	109.27	117.36	
RES-C42-GH	0.249	0.000	0.644	0.367	0.227	3.255	1.500	0.072	1.790	1.603	2.887	0.016	
SEP-C42-GH	0.057	0.000	0.727	1.712	0.063	4.520	4.194	0.178	4.754	4.676	3.23	0.000	
POS APN-AR	5.46	3.42	6.58	6.72	3.46	8.28	9.06	3.85	5.63	4.64	5.42	1.13	
APN DELTA	2.04	0.00	3.12	3.26	0.00	4.43	5.21	0.00	4.50	3.51	4.29	0.00	
TOT CHN	71.96	75.20	77.33	78.30	77.96	89.48	92.63	93.08	112.71	108.08	115.81	117.37	
DELTA CHN	-3.24	0.00	-0.62	0.35	0.00	-3.60	-0.46	0.00	-4.66	-9.29	-1.55	0.00	
NA-AVN	18.17	26.54	13.80	15.93	24.64	14.53	18.94	30.34	20.46	19.93		41.01	
DELTA NA-AVN	-8.37	0.00	-10.83	-8.70	0.00	-15.81	-11.41	0.00	-20.55	-21.08		0.00	
AVAIL NEG	9.12	17.49	8.34	10.47	19.17	7.69	12.09	23.50	9.81	9.28		30.36	
DELTA AVN	-8.37	0.00	-10.83	-8.70	0.00	-15.81	-11.41	0.00	-20.55	-21.08		0.00	
POS THK(NIL)	29.4	29.2	29.7	29.7	29.6	30.4	28.6	29.8	32.2	32.0	31.3	29.1	
NOM SPEC	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	
NEG THK(NIL)	33.5	31.4	31.1	32.2	30.1	32.7	31.8	31.9	31.0	31.4	31.4	31.0	
NOM SPEC	31.5	31.5	29.1	29.1	29.1	31.5	31.5	31.5	29.9	29.9	29.9	29.9	
KON QTY (NL)	81.0	81.0	85.0	82.0	85.0	100.0	100.0	102.0	120.0	120.0	120.0	124.5	
IK2C03 I	6.60	6.07	7.05	7.51	5.13	5.50	5.22	3.87	6.76	5.04	N/A	3.89	
NOTE: THK FOR BASELINE CELLS IS FROM DRY PACK JUST BEFORE INSERTION INTO CASE. THK FOR DPA POS IS ON LOADED PLATE, FOR DPA NEG IS ON DELOADED PLATE.													

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November 1-3, 1988

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TASK GROUP PRESENTATION:

7. QUALITY OVERSIGHT TASK GROUP

(NOT SUBMITTED)

C. LAURIE, TRW

SESSION II

NICKEL-CADMIUM CELL TESTING

Chairman: T. Yi, NASA/GSFC



G.E. ASTRO SPACE DIVISION



ADVANCED DESIGN

NICKEL CADMIUM CELLS

IR&D

1985 → 1988

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November 1-3, 1988

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100 A.H. NiCd CELLS



	100AB07	100EC08	100EC09
	CHEMICALLY DEPOSITED	ELECTROCHEMICALLY DEPOSITED	ELECTROCHEMICALLY DEPOSITED
PLATE TREATMENT	SILVER IN NEGATIVE	NO TREATMENT	NO TREATMENT
SEPARATOR	PELLON 2536	ZIRCAR UNTREATED	PELLON 2536
NUMBER OF PLATES	16 POS 17 NEG	16 POS 17 NEG	17 POS 18 NEG
PLATE CAPACITY A.H. BY ANALYSIS	152.3 POS 246.3 NEG	113.6 POS 235.3 NEG	120.7 POS 249.1 NEG
CELL WEIGHT KILOGRAMS	3.30	3.22	3.18
CONDITIONING CYCLE 20°C	97.5 A.H. 36.3 WH/Kg	89.2 A.H. 34.1 WH/Kg	93.8 A.H. 36.3 WH/Kg
3RD CAPACITY @ 20°C	99.8 A.H. 37.2 WH/Kg	92.3 A.H. 35.3 WH/Kg	96.0 A.H. 37.1 WH/Kg
POSITIVE UTILIZATION	65.5%	81.2%	79.5%
CC KOH CC/AH	261 2.62	406.5 4.40	364 3.79
A.H TO REACH MAX VOLTAGE	141 @ 20°C 139 @ 15°C	111 @ 20°C 109 @ 15°C	115 @ 20°C (118 @ 15°C)**
3RD CAPACITY @ 15°C	105 A.H. 39.1 WH/Kg	93.7 AH 35.8 WH/Kg	99.4 AH 38.4 WH/Kg

**CHARGE INTERRUPTED



E. D. POSITIVE PLATE



WHAT IS IT

- E. D. Means "Electro-Deposited" Impregnation As Opposed To Chemical Impregnation

It Is Also Sometimes Called E. C. Or Electro-Chemically Deposited

ADVANTAGES

- Longer Life - Anticipate 10 To 15 Years Of Orbital Life At 0 To 10°C Operation
- Virtually No Nickel Attack
- Virtually No Plate Swelling Resulting In Greater Mechanical Stability
- Improved Conductivity
- Used in NiH₂ Cells

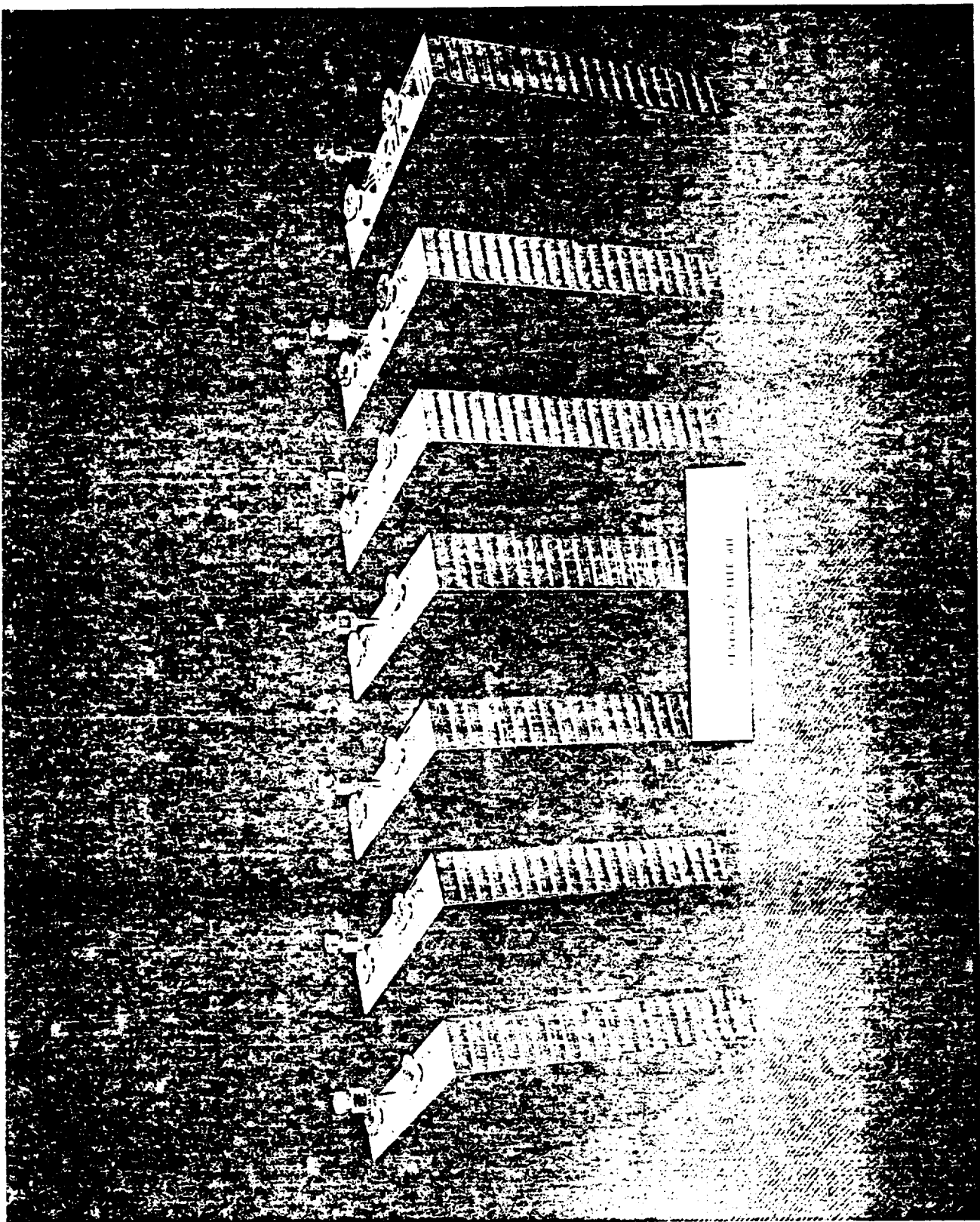
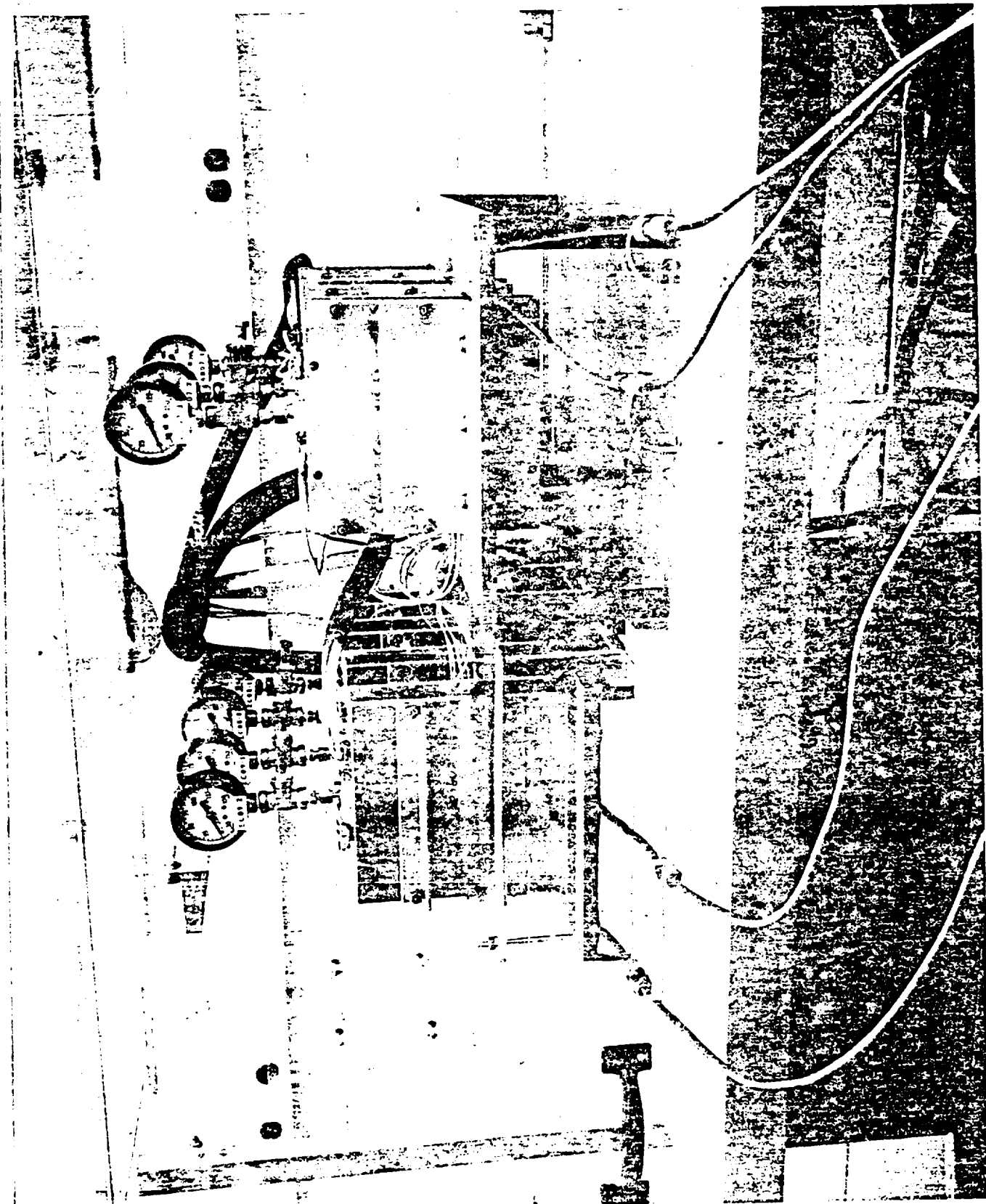


FIG 7 SEVEN NiCd CELLS DELIVERED BY GATES

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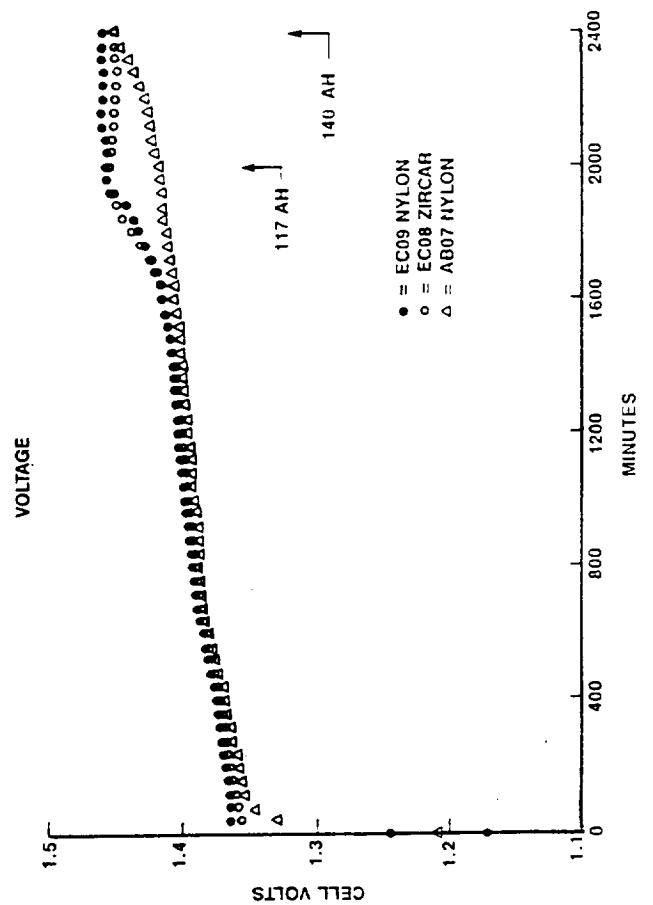
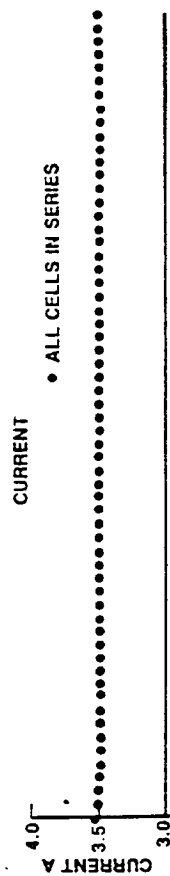
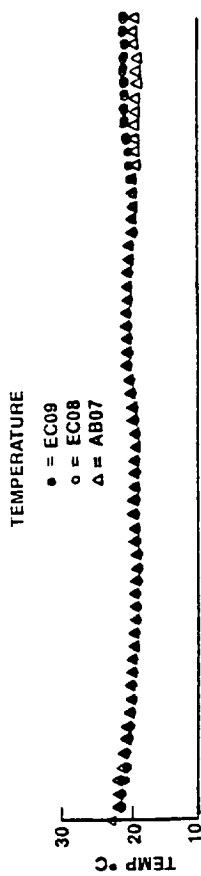
November 1-3, 1988

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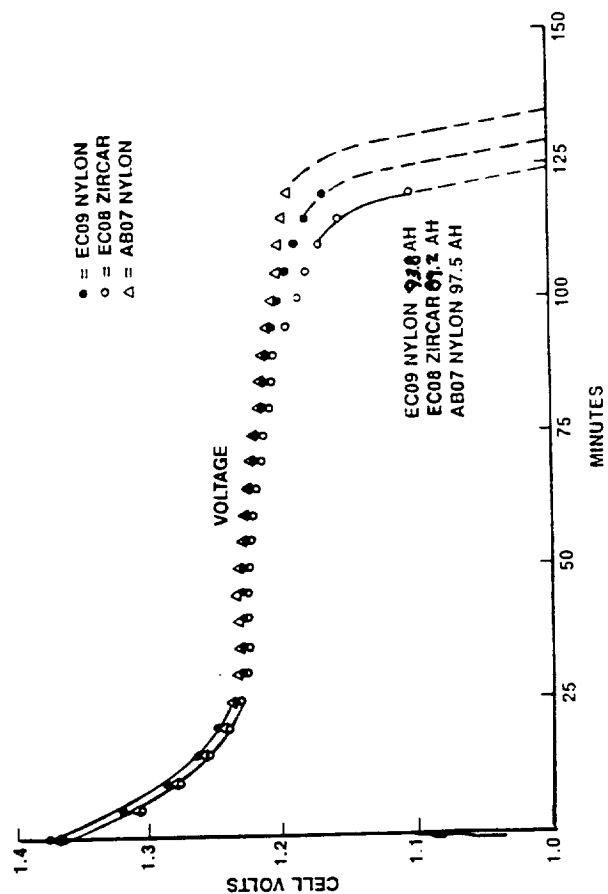
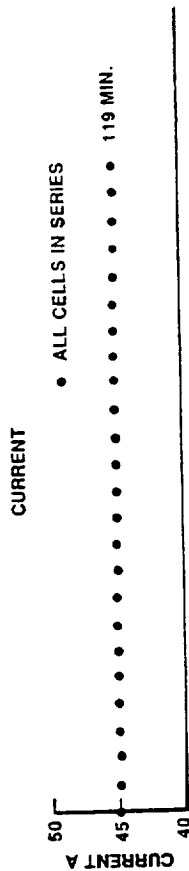
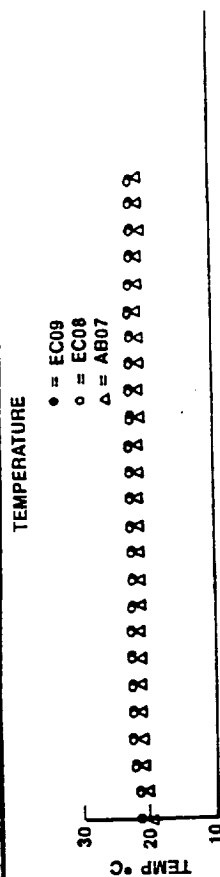


100 A.H. Ni Cd CELLS
CONDITIONING CYCLE #2 CHARGE
2/24 TO 2/26/88



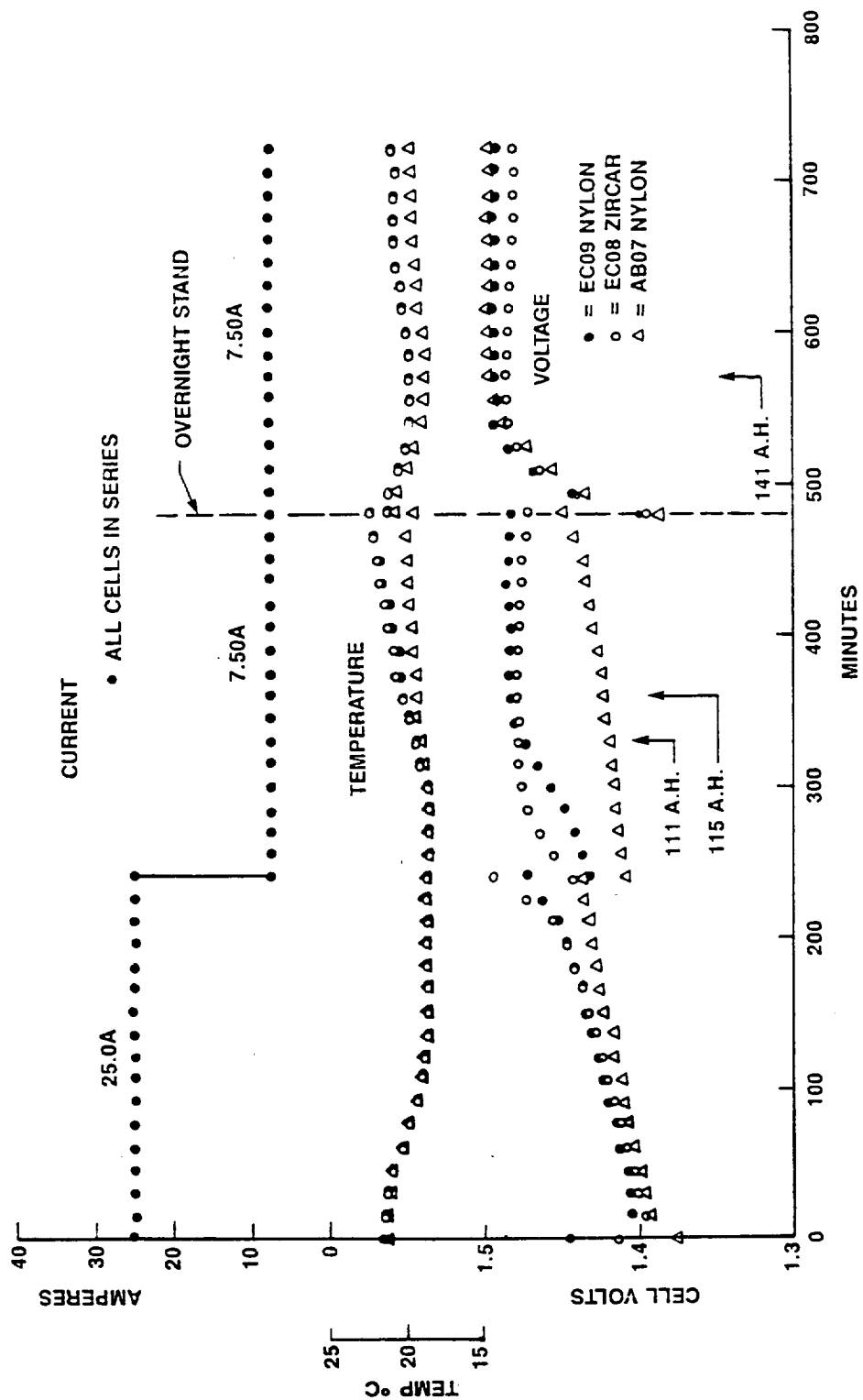


100 A.H. NI Cd CELLS
CONDITIONING CYCLE #2 DISCHARGE
2/26/88



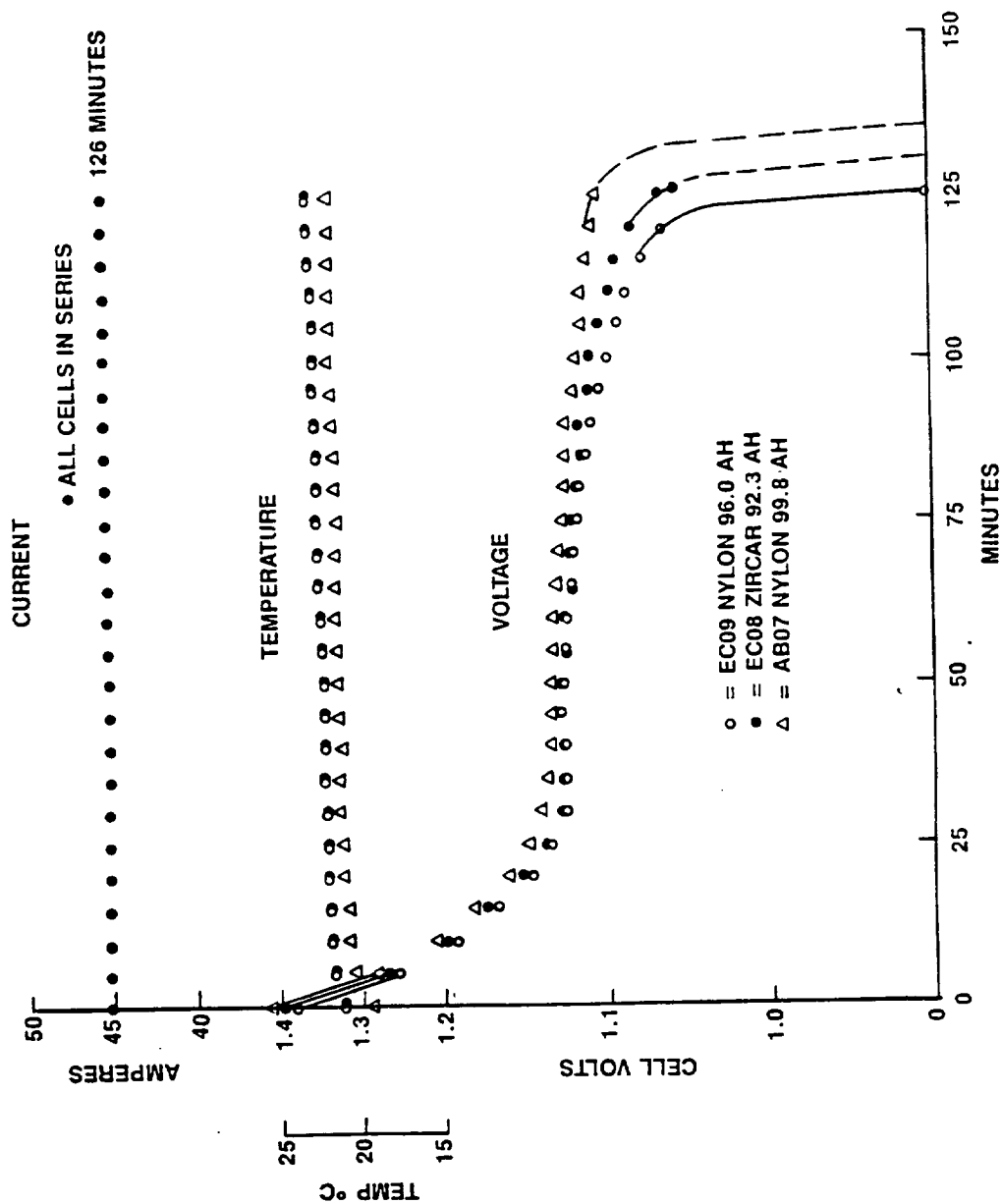


100 A.H. Ni Cd CELLS
3RD CAPACITY TEST AT 20°C - CHARGE
3/30/88 & 3/31/88



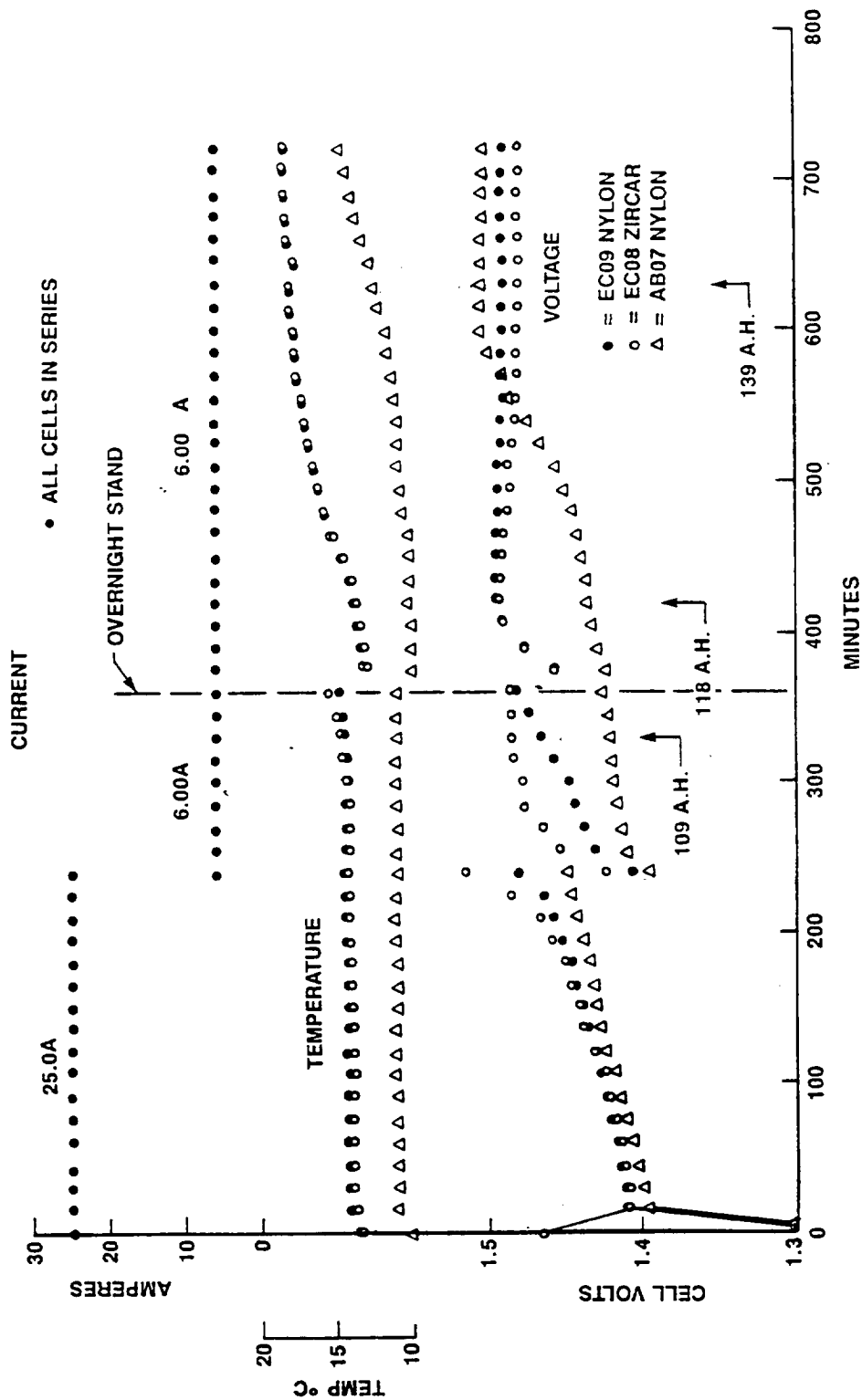


100 A.H. Ni Cd CELLS
3RD CAPACITY TEST AT 20°C - DISCHARGE
3/31/88



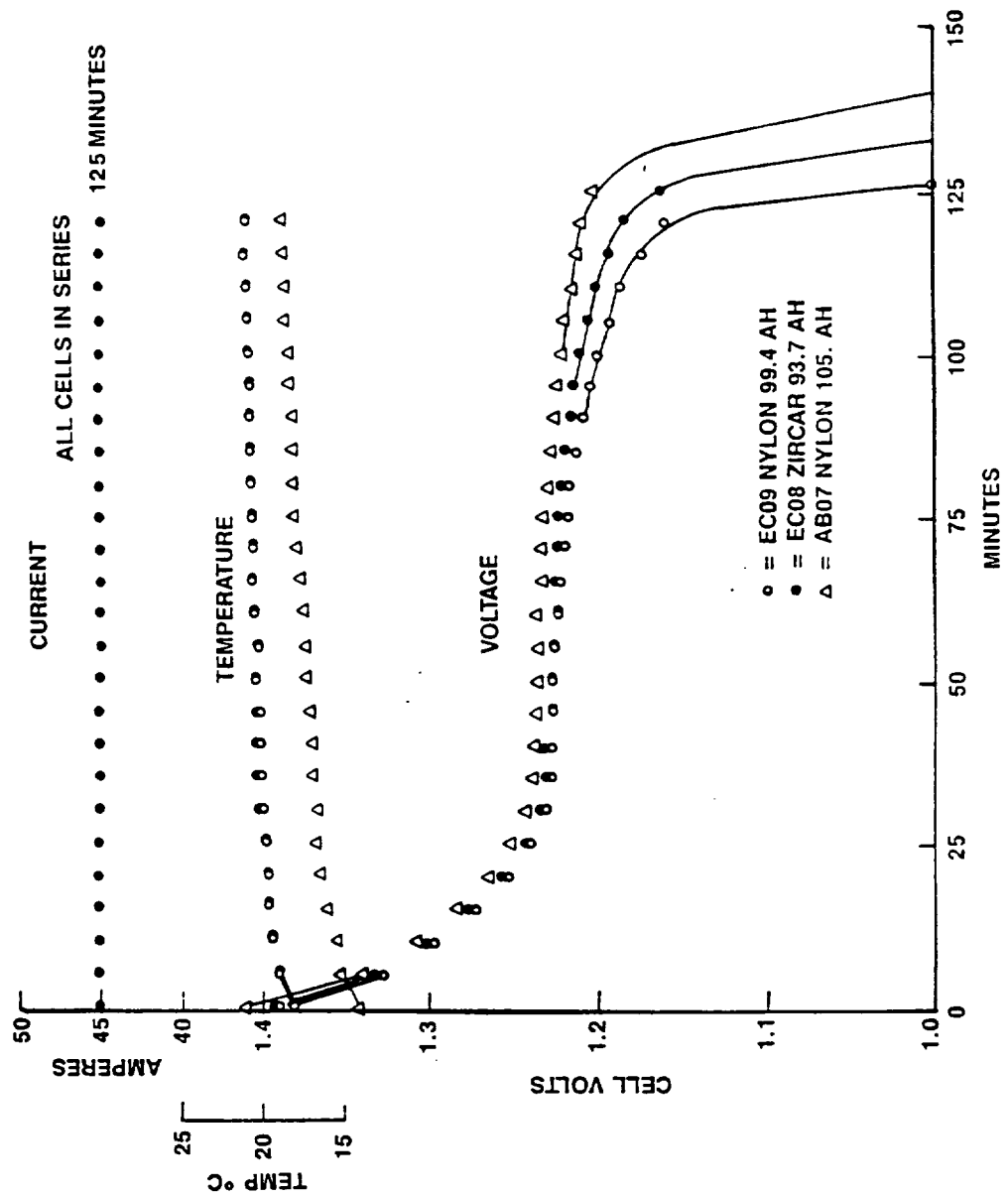


100 A.H. Ni Cd CELLS
3RD CAPACITY TEST AT 15°C - CHARGE
4/19/88 & 4/20/88



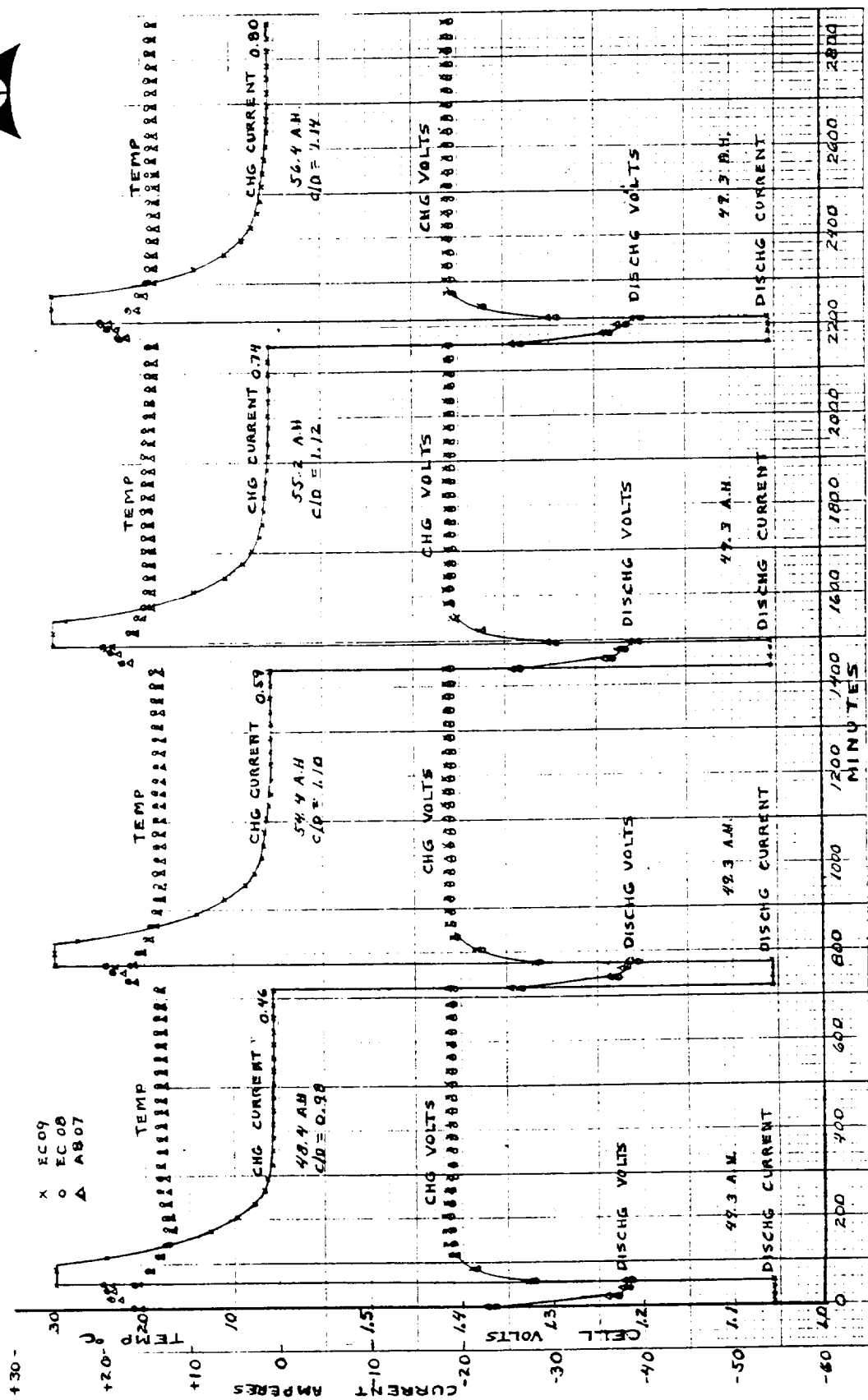


100 A.H. Ni Cd CELLS
3RD CAPACITY TEST AT 15°C - DISCHARGE
4/20/88



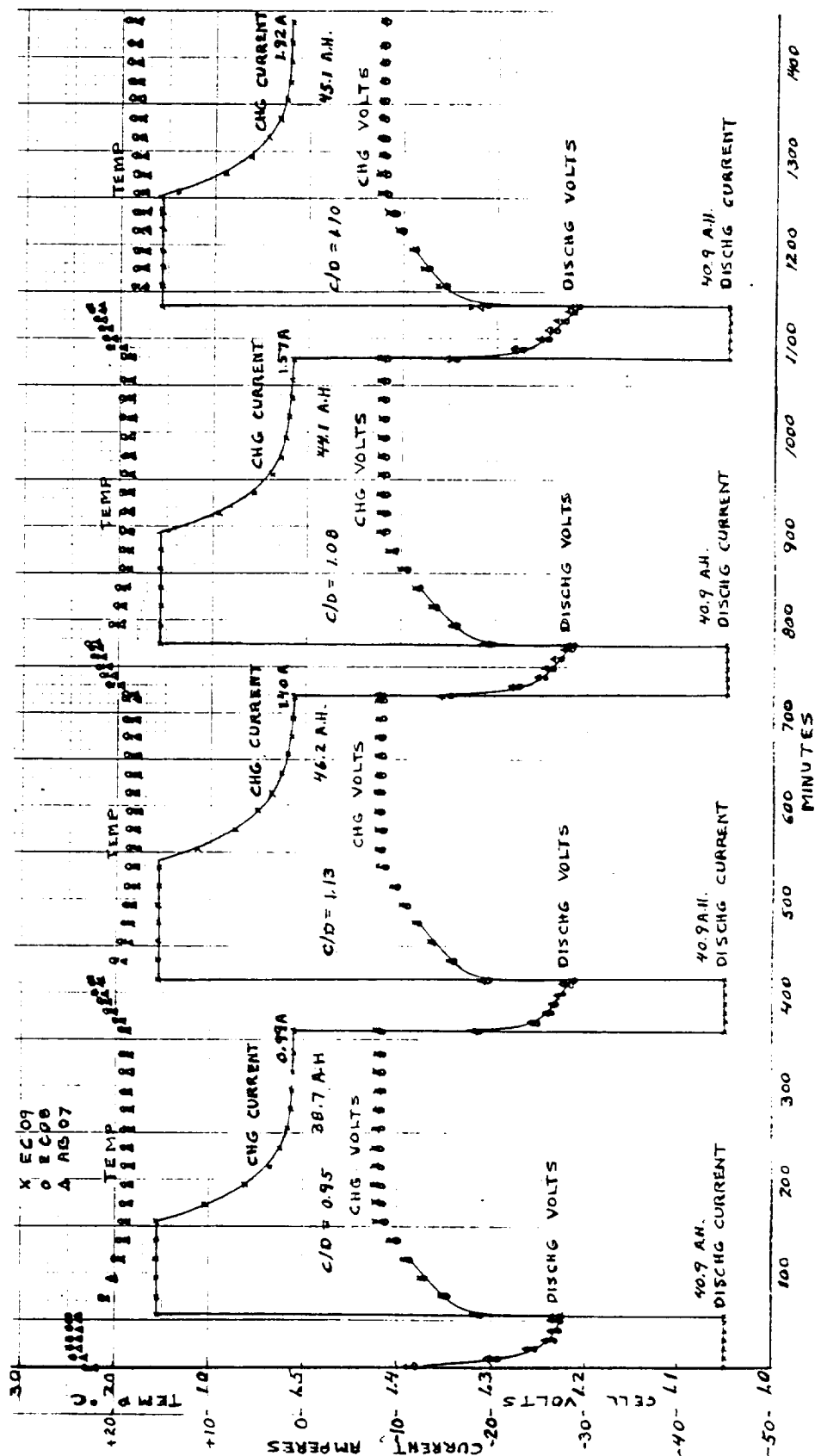


100 A.H. NiCd CELLS
55 MINUTE DISCHARGE AT 54.3 A
655 MINUTE CHARGE AT 25.0 A PLUS V/T #2
20°C 50% DOD 8/24/88 TO 8/26/88

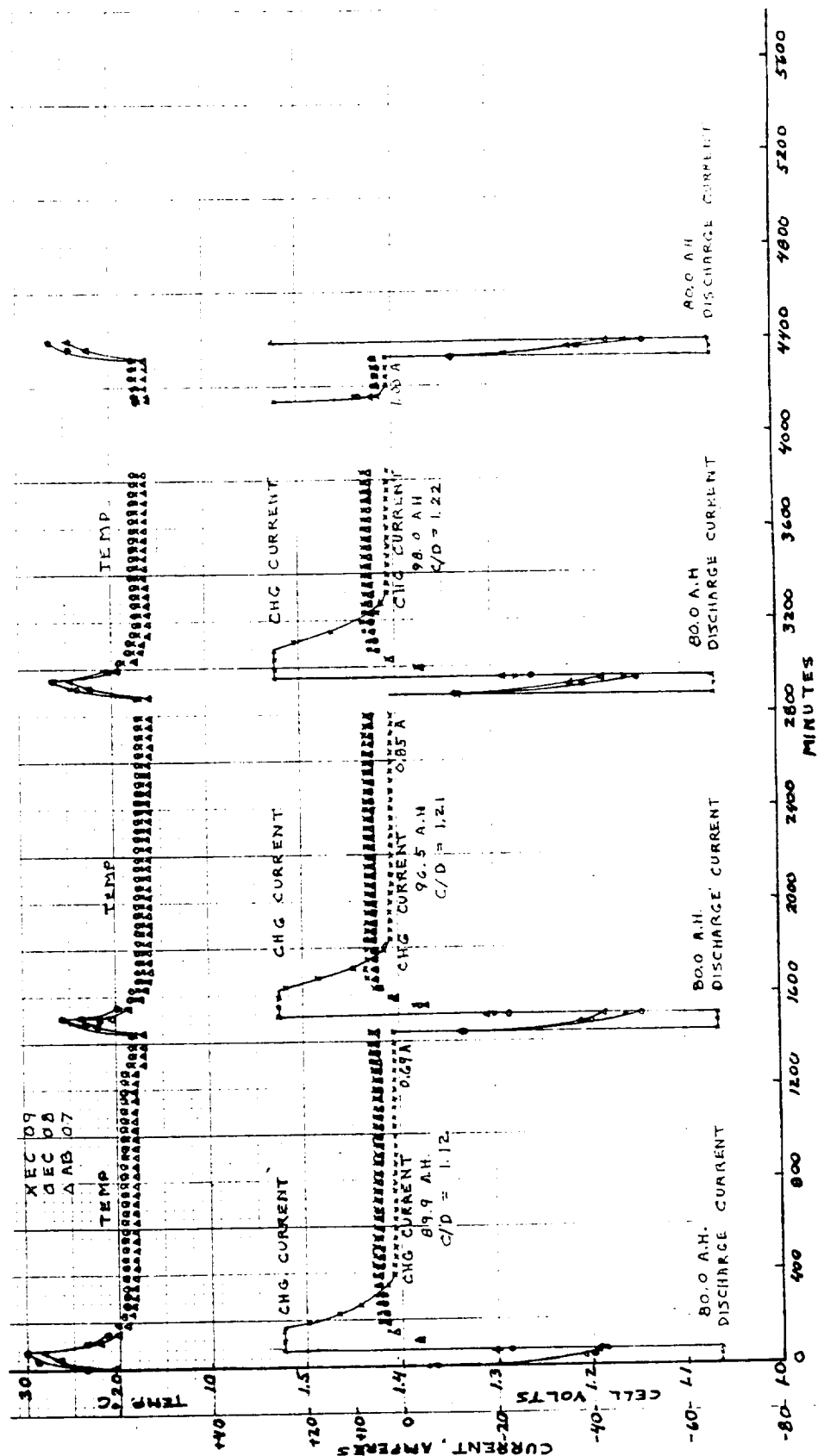




100 A.H. NiCd CELLS
55 MINUTE DISCHARGE AT 45.0 A
305 MINUTE CHARGE AT 15.7 A PLUS V/T #2
20°C 41% DOD 8/31/88 TO 9/2/88



100 A.H. NiCd CELLS
 72 MINUTE DISCHARGE AT 66.7 A
 1368 MINUTE CHARGE AT 25 A PLUS V/T #2
 20°C 80% DOD 10/21/88 TO 10/28/88





100 A.H. NiCd CELLS

SUMMARY



- ED PLATES HAVE HIGHER ACTIVE MATERIAL UTILIZATION
 - REQUIRE LIGHTER LOADING OF POSITIVE PLATES
 - HIGH POROSITY PERMITS HIGH ELECTROLYTE ADDITION
>3.5 CC/AH
- SPECIFIC ENERGY OF CD AND ED CELLS ABOUT EQUAL
 - 37.1 WH/KG (16.9 WH/LB) AT 20°C
- ED CELLS CHARGE MORE EFFICIENTLY
 - SAVES TEST TIME
 - SAVES SOLAR ARRAY ENERGY
- CHARGE VOLTAGE OF CD AND ED CELLS NOT SIGNIFICANTLY DIFFERENT
 - TEMPERATURE COMPENSATED CHARGE CONTROL APPLICABLE TO BOTH

SAFT Ni-Cd LIFE TEST DATA UNDER GEO AND LEO CYCLING

**J.VERNIOLLE, B.Hendel-Wormann & A.Sepers
European Space Agency / Estec**

**NASA/GSFC Battery Workshop
November 1988**

November 1-3, 1988

**ORIGINAL PAGE IS
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- LEO TESTING:
 - ELAN PROGRAM
 - X-80 TEST
- GEO TESTING:
 - ACC. HIGH DOD TEST
 - OTS REAL SIMULATION

ELAN LOW EARTH ORBIT TESTING

Joint ESA/CNES program on Ni-Cd

12 cell battery assembly on cold plate

18 SAFT Bat.(13 VO24S,4 VO40S3,1 VOS20B)

1 G.E Bat.(22 Ah)

Cycling profile derived from SPOT

35mn discharge (last 10' at higher rate)

65 min charge (VL(T) tapering)

DOD : 10%, 20%, 30% & 40%

COLD PLATE TEMP.: -5, +5, +15, +25 Deg.C

Battery	%DOD	Deg.C	Idc1(A)	Idc2(A)	Ich(A)	#cycl.	Veod (V)
VO24S	10	+5				17387	1.246*
		+15	3.45	5.77	8	17395	1.247*
		+25	(0.14C)	(0.24C)	(0.33C)	17387	1.213*
	20	-5				15647	1.135*
		+5	3.45	20.0	8	17413	1.104
		+15	(0.14C)	(0.83C)	(0.33C)	15779	1.083
		+15				17395	1.136*
		+25				17379	1.104
	30	-5	7.00	26.00	12	15621	1.069*
		+5	(0.29C)	(1.08C)	(0.5C)	17412	1.037
		+15				15780	1.035
	40	+5	7.00	40.00	16	17389	0.995**
			(0.29C)	(1.67C)	(0.67C)		
		+25	15.00	20.00	16	17361	1.007***
			(0.62C)	(0.83C)	(0.67C)		
VO40S3	10	+5	6.8	6.8	10	7532	1.269*
			(0.17C)		(0.25C)		
	20	+5	13.7	13.7	10	7542	1.218*
			(0.34C)		(0.25C)		
	30	+15	20.0	25.00	20	10559	1.079
			(0.5C)	(0.62C)	(0.5C)		
	30	+25				10536	1.087
VOS20B	30	+15	5.8	21.55	10	6831	1.062
			(0.29C)	(1.08C)	(0.5C)		
G.E 22Ah	20	+15	3.28	18.28	7.38	12231	1.06
			(0.15C)	(0.83C)	(.33C)		

* Reconditioning EVERY 6 MONTHS

After nominal DOD, DC with I1 down to 12V

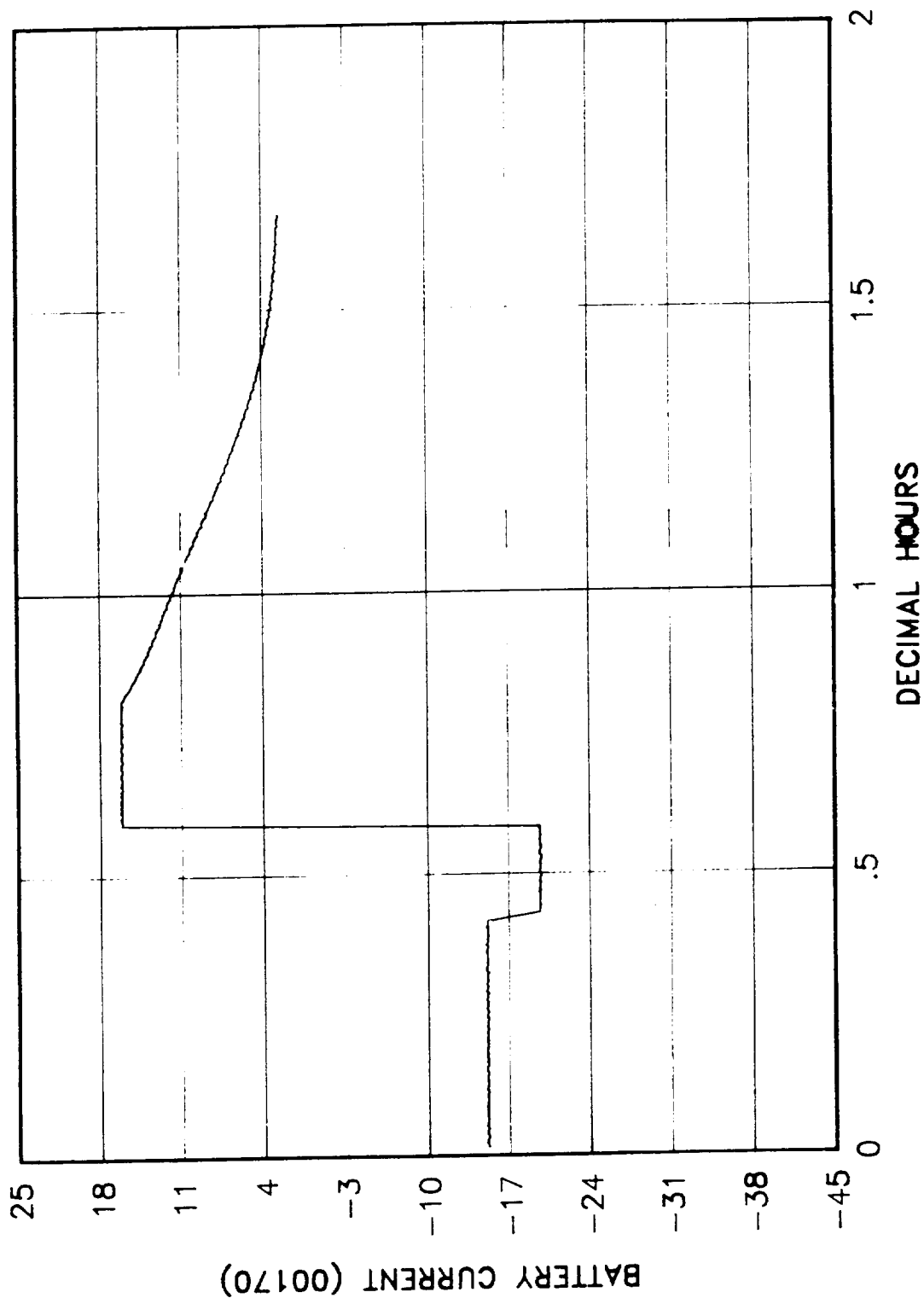
** Reconditioned at cycle 15081

*** Cycle condition changed at cycle 1350

ELAN PROGRAM : TEST STATUS ON OCT. 24th/1982

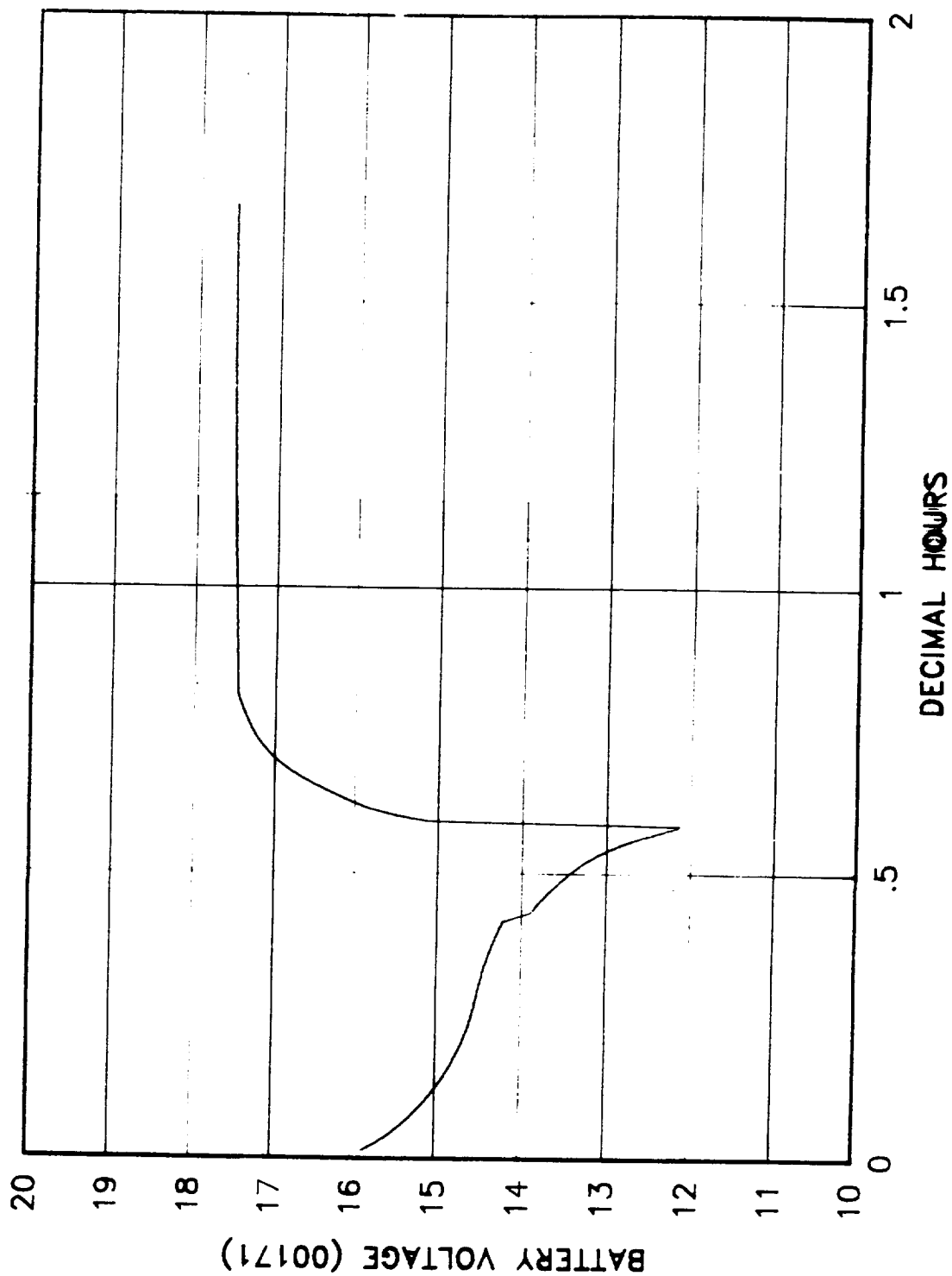
ELAN Battery no. 14, bay no. 12
 Nominal Dod 40%, Nominal temp 25 deg c
 STARTING AT 04,10,88,23,01,27 (CYC 01 REP 17073)

Typical cycle of battery current



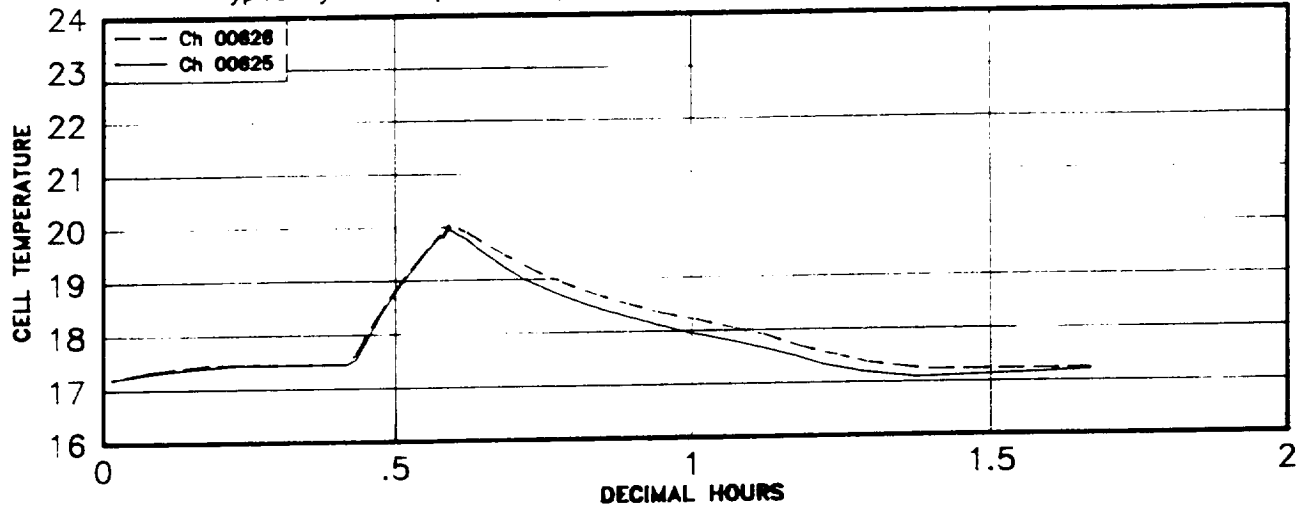
ELAN Battery no. 14, bay no. 12
 Nominal Dod 40%, Nominal temp 25 deg q
 STARTING AT 04,10,88,23,01,27 (CYC 01 REP 17073)

Typical cycle of battery voltage

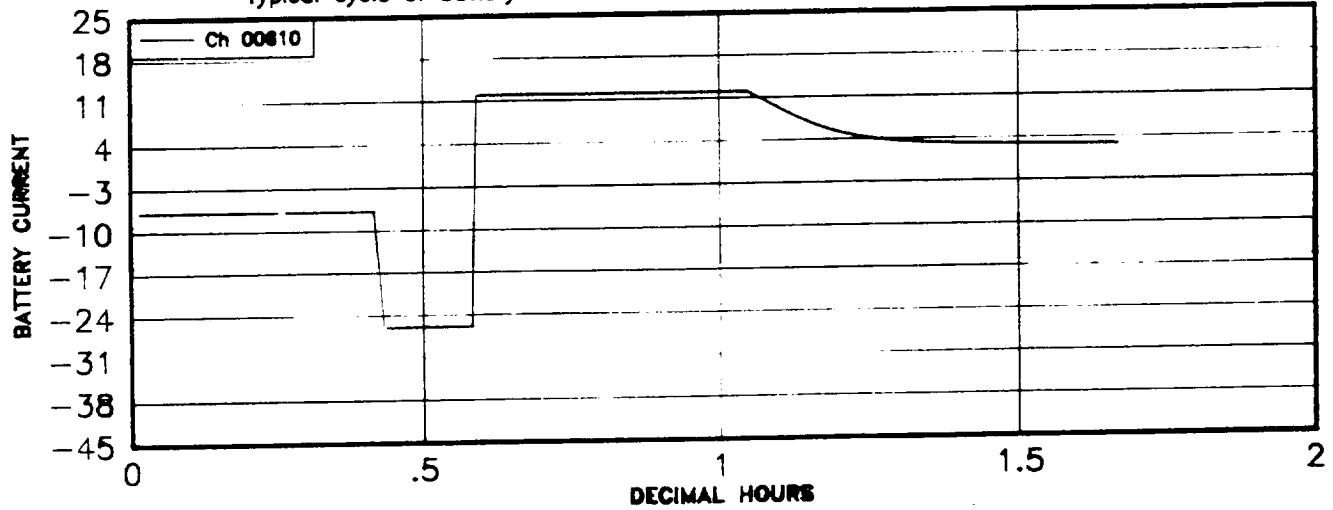


ELAN Battery no. 15, bay no. 27
Nominal DOD 30%, Nominal temp 15 deg c
STARTING AT 30,09,88,21,41,46 (CYC 01 REP 15433)

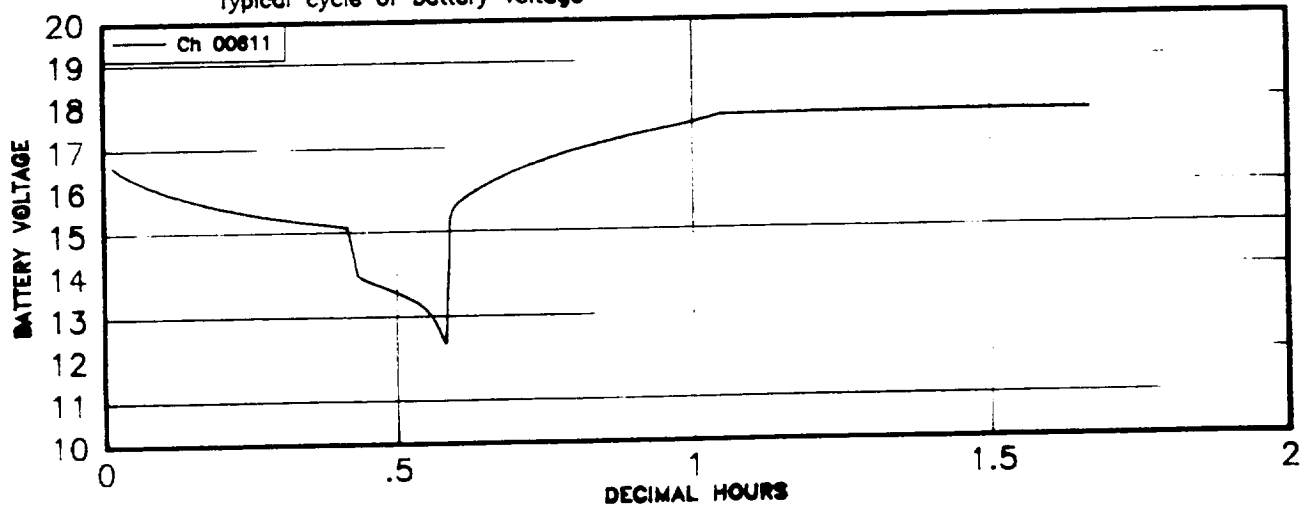
Typical cycle of top cell temperatures

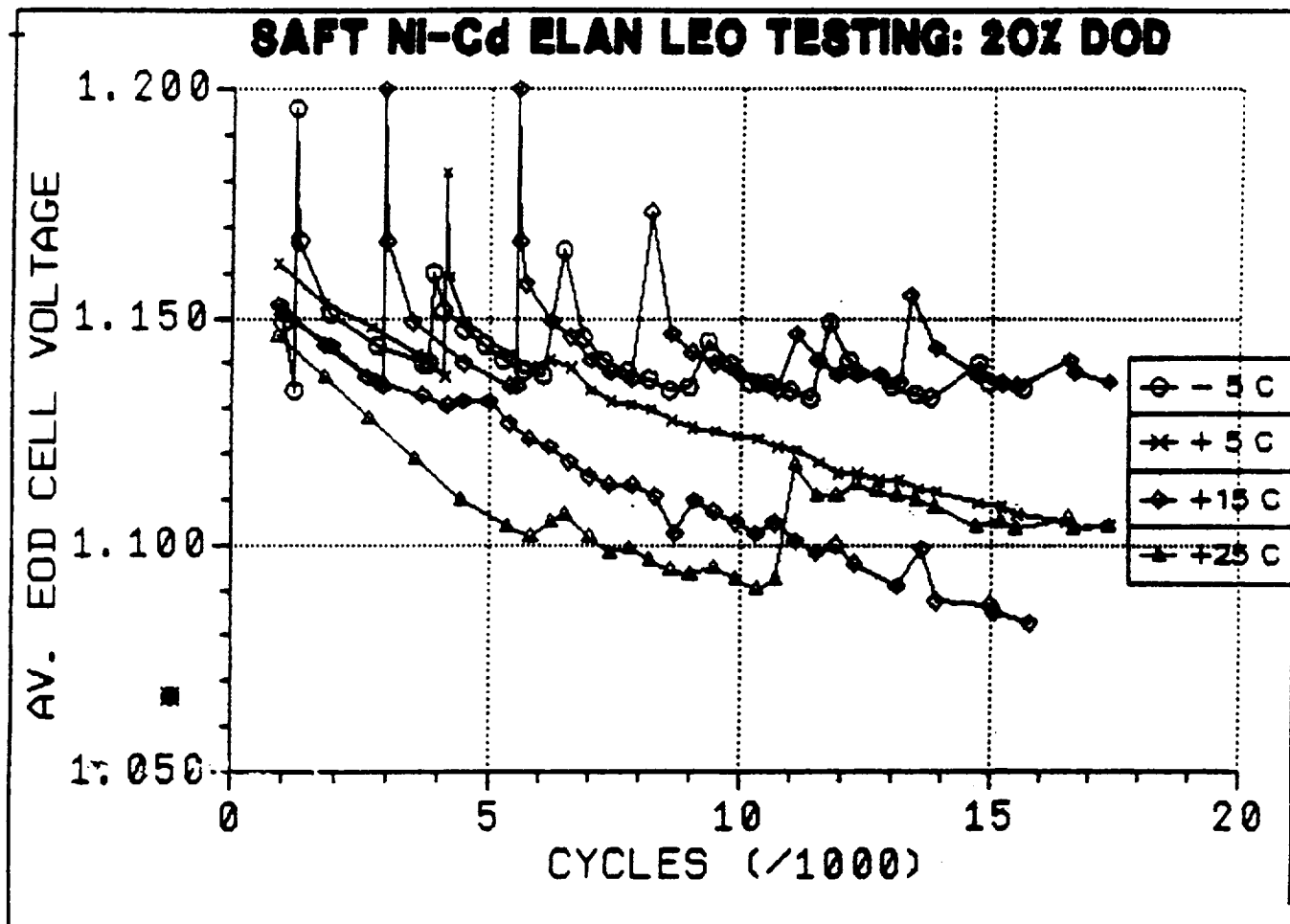


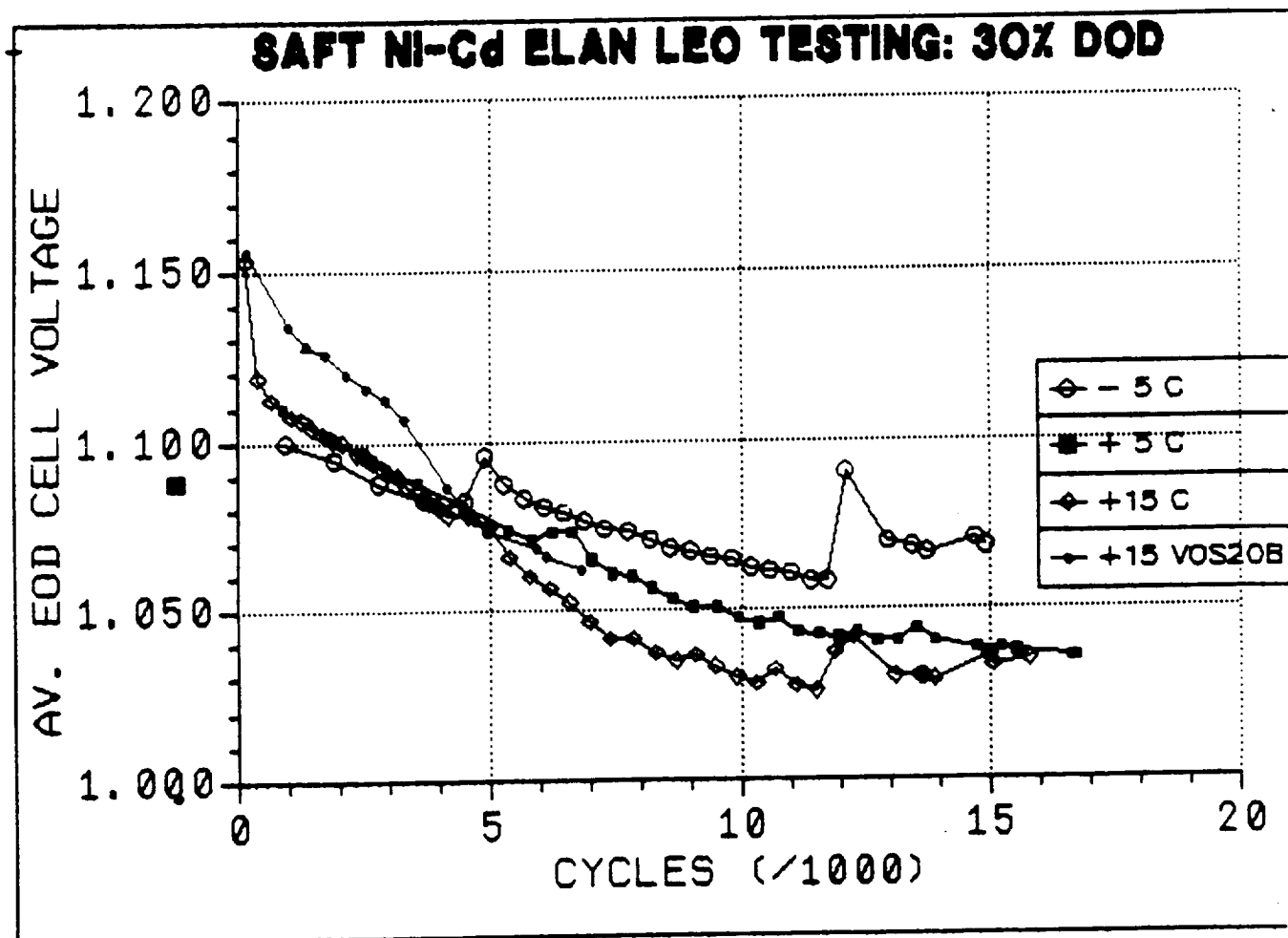
Typical cycle of battery current



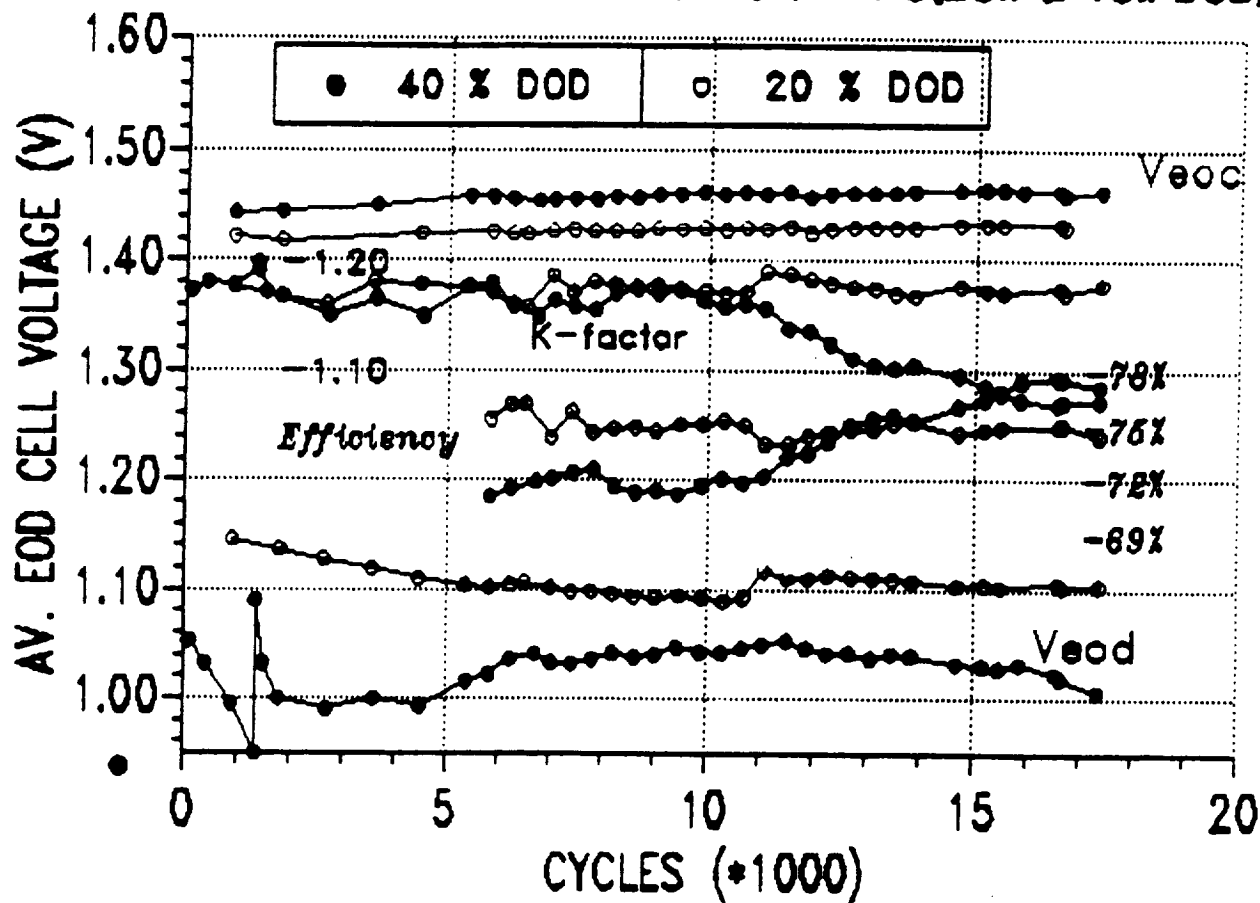
Typical cycle of battery voltage



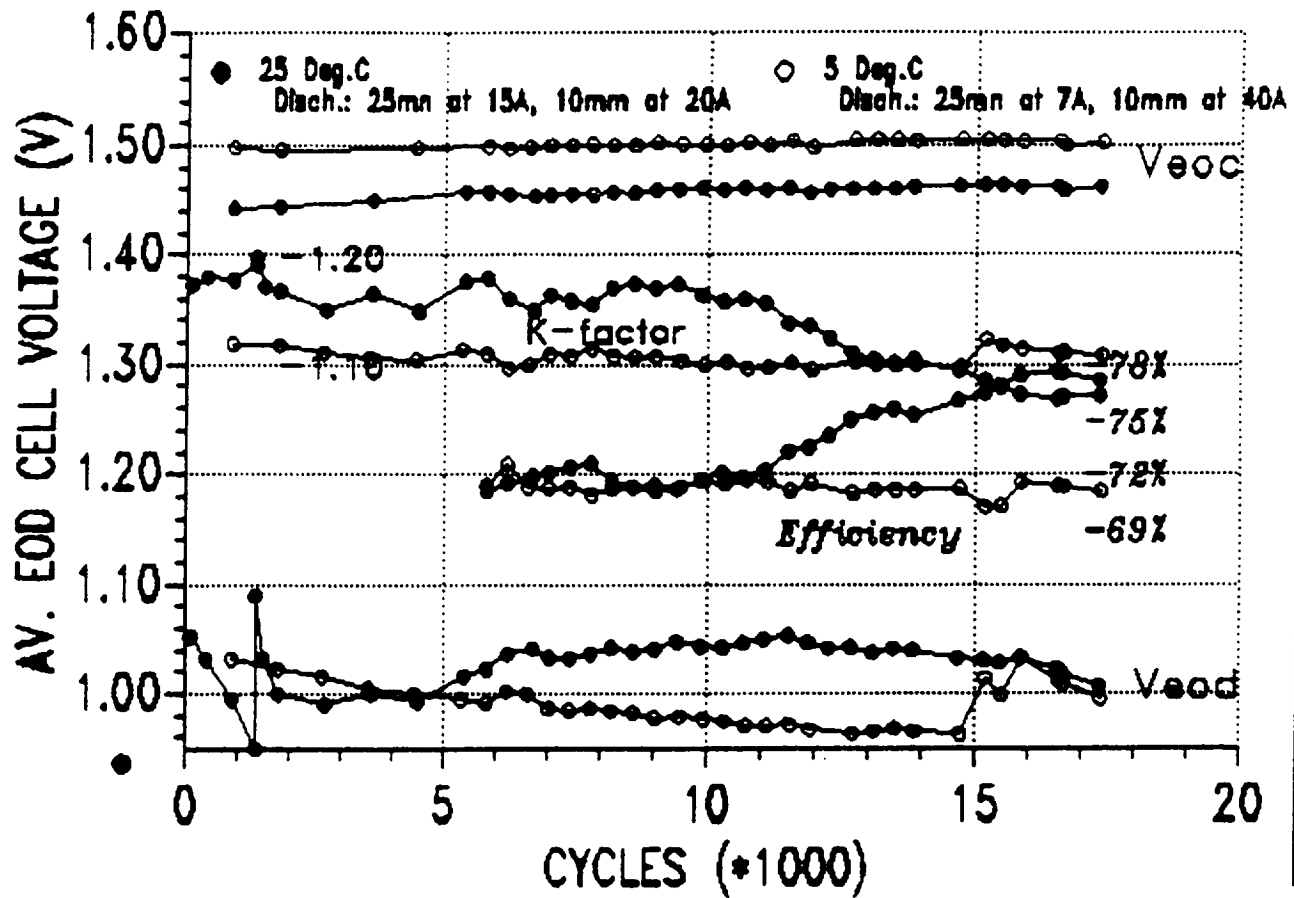




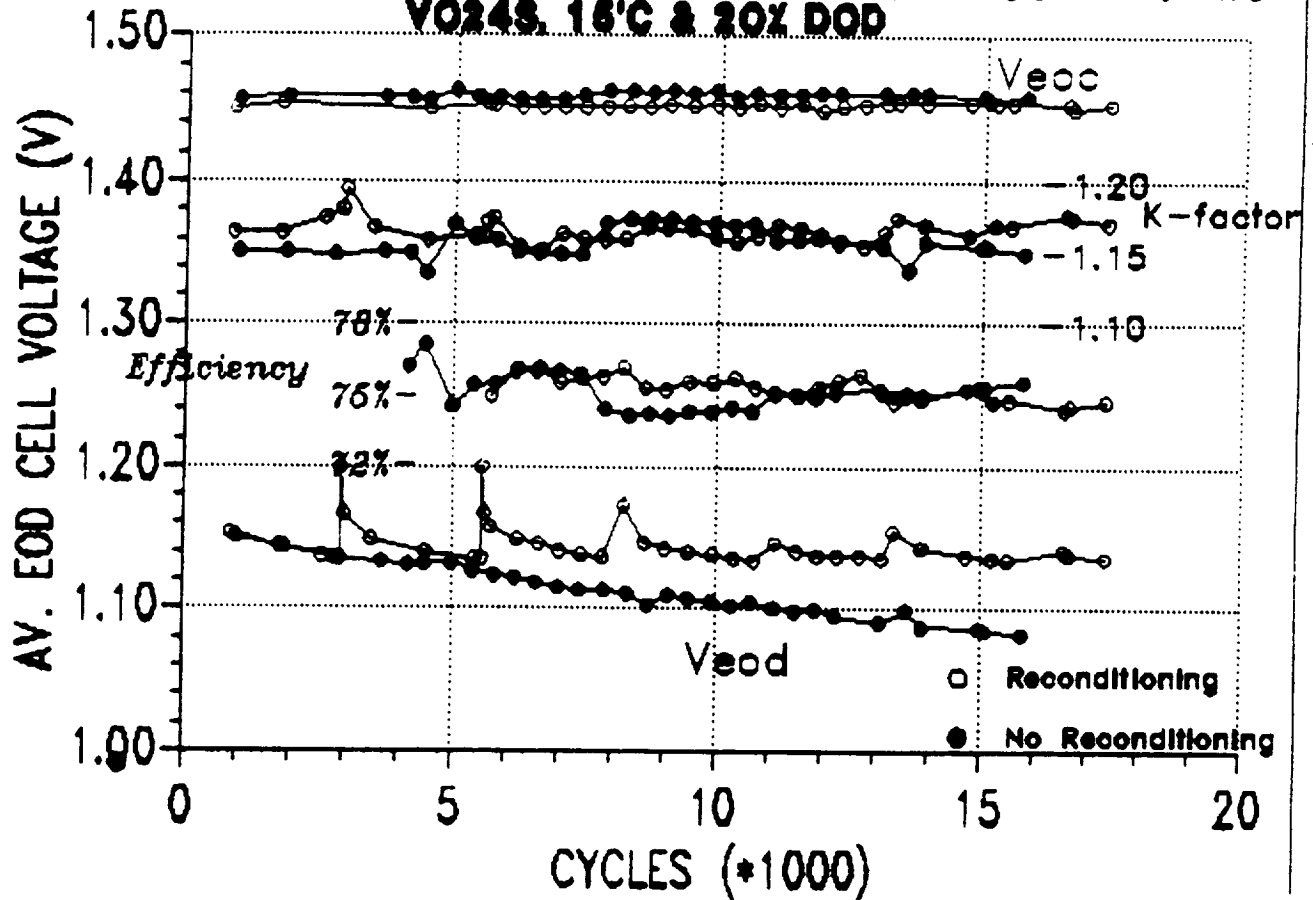
SAFT NI-Cd ELAN LEO TESTING: VO248 at 25°C (20% & 40% DOD)



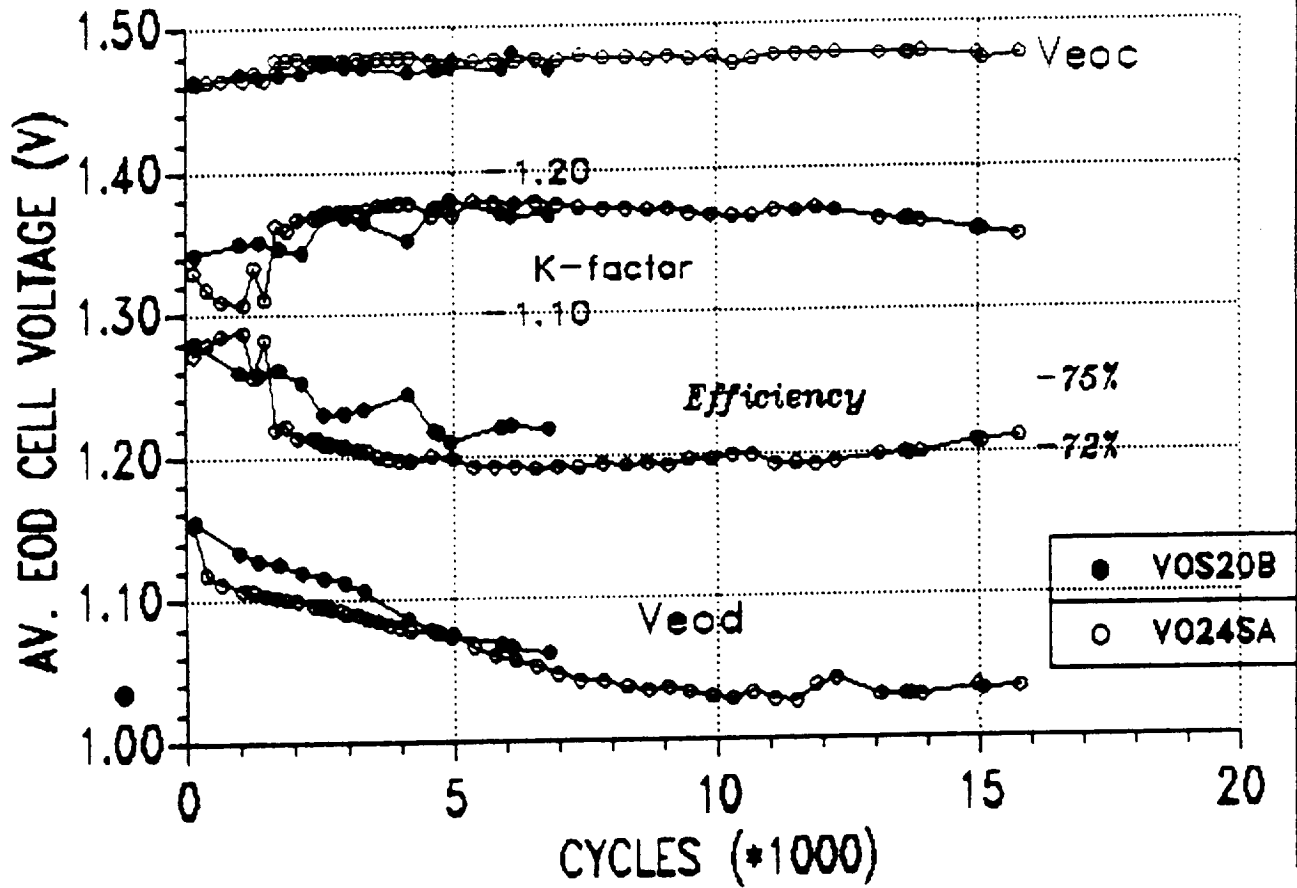
SAFT NI-Cd ELAN LEO TESTING: VO24S at 40% DOD

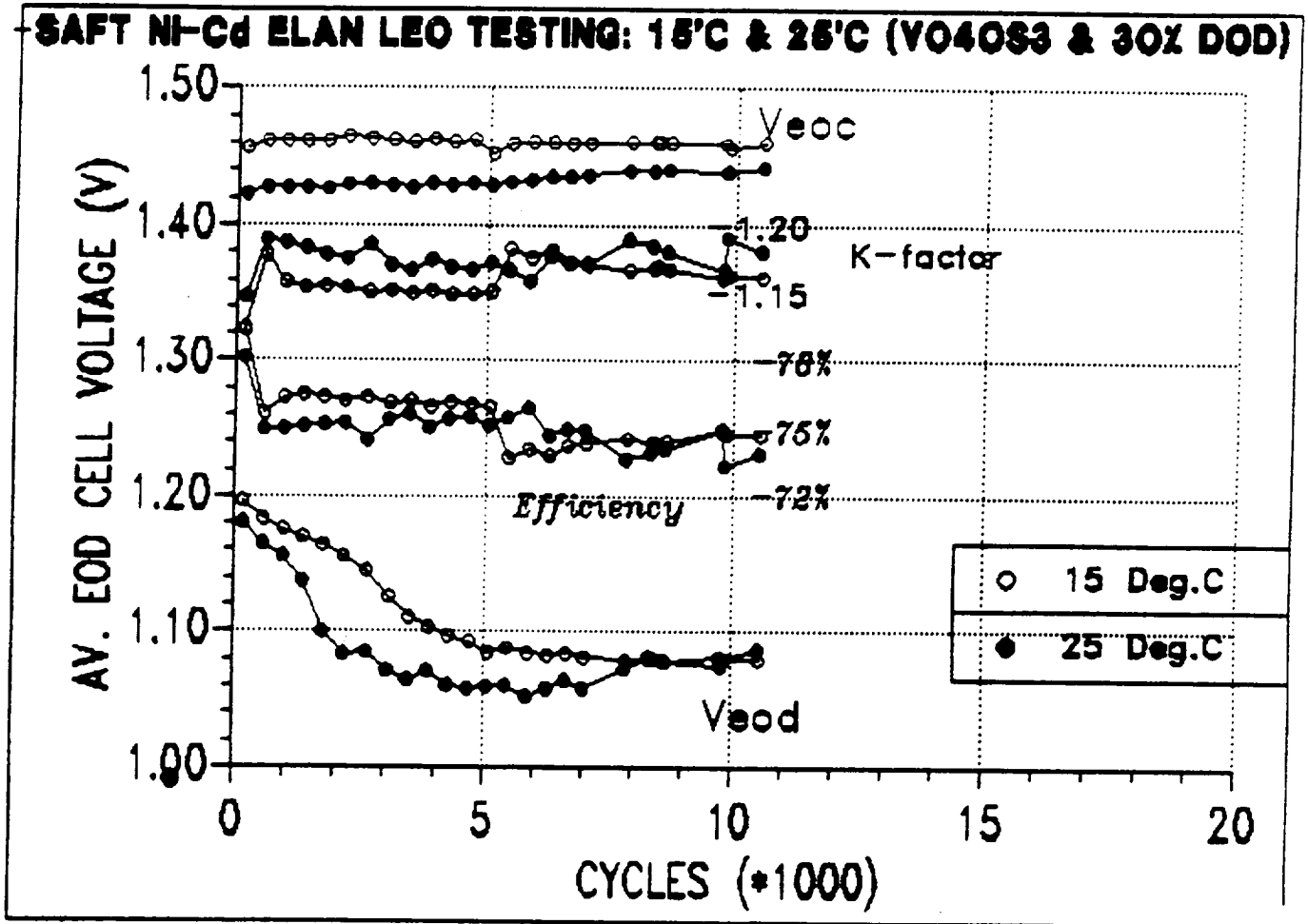


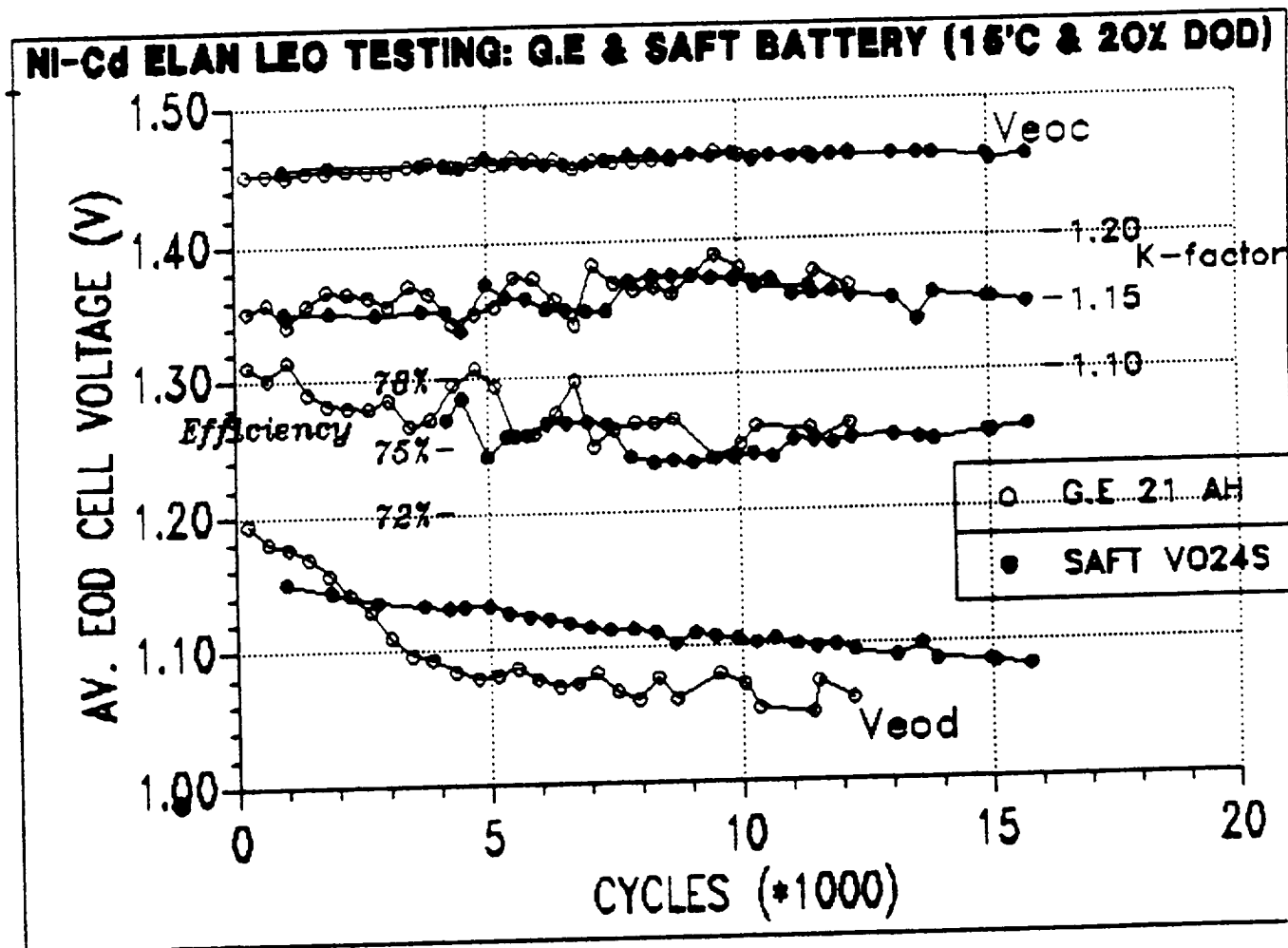
**SAFT NI-Cd ELAN LEO TESTING: INFLUENCE OF RECONDITIONING
VO243, 16'C & 20% DOD**



SAFT NI-Cd ELAN LEO TESTING: VOSA & VOSB (30% DOD & 15°C)







ELAN LOW EARTH ORBIT TESTING

Very good battery performance

No failure observed

Cycling at 40% exceeds previsions

Effect of reconditioning is substantial

X-80 LEO LIFE TEST

Initiated for an X-ray astronomy mission

14 SAFT cell 23Ah battery

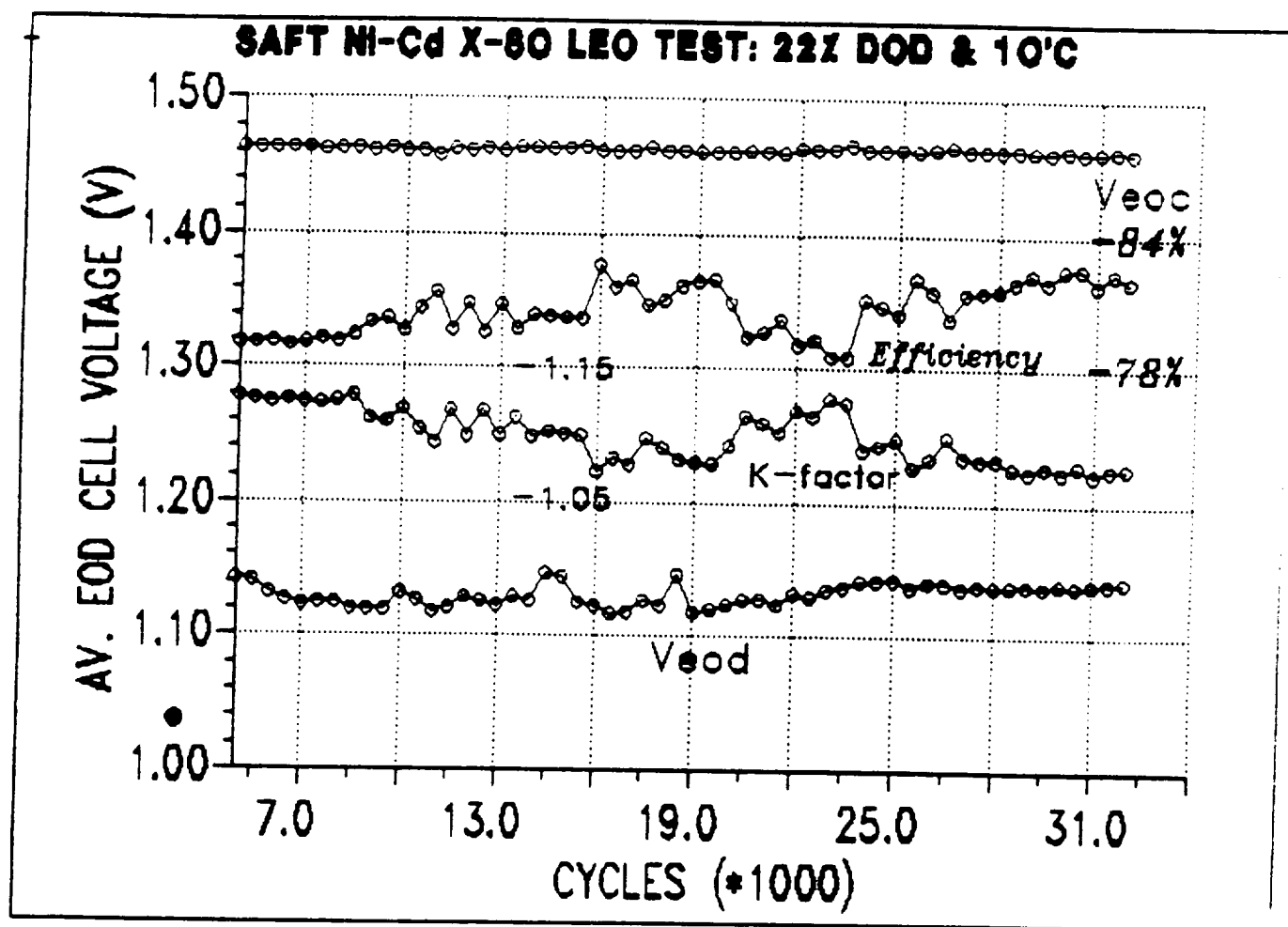
35mn discharge, DOD 22%

Const. I charge to a set volt. (61mn max)

Battery in chamber at 10 deg.C

Test started in Nov.1981, still running

32000 cycle achieved with no degradation



- NICd HIGH DOD ACCELERATED GEO TEST

3 ex-ECS1 28 SAFT cell 18AH Bat.

2 FM (V018S3), 1 EM (V018S)

Batteries on same cold plate

FM no.6 : 100% DOD max

FM no.5 : 90% DOD max

EM no.1 : 70% DOD max

- **NICd HIGH DOD ACC.GEO TEST CONDITIONS**

Eclipse season : 45 cycles

-9 periods of 5 cycles of 24 hours

-Disch.rate for DOD max at 5th period

-C/10 charge to $K=1.05$ or back-up volt.

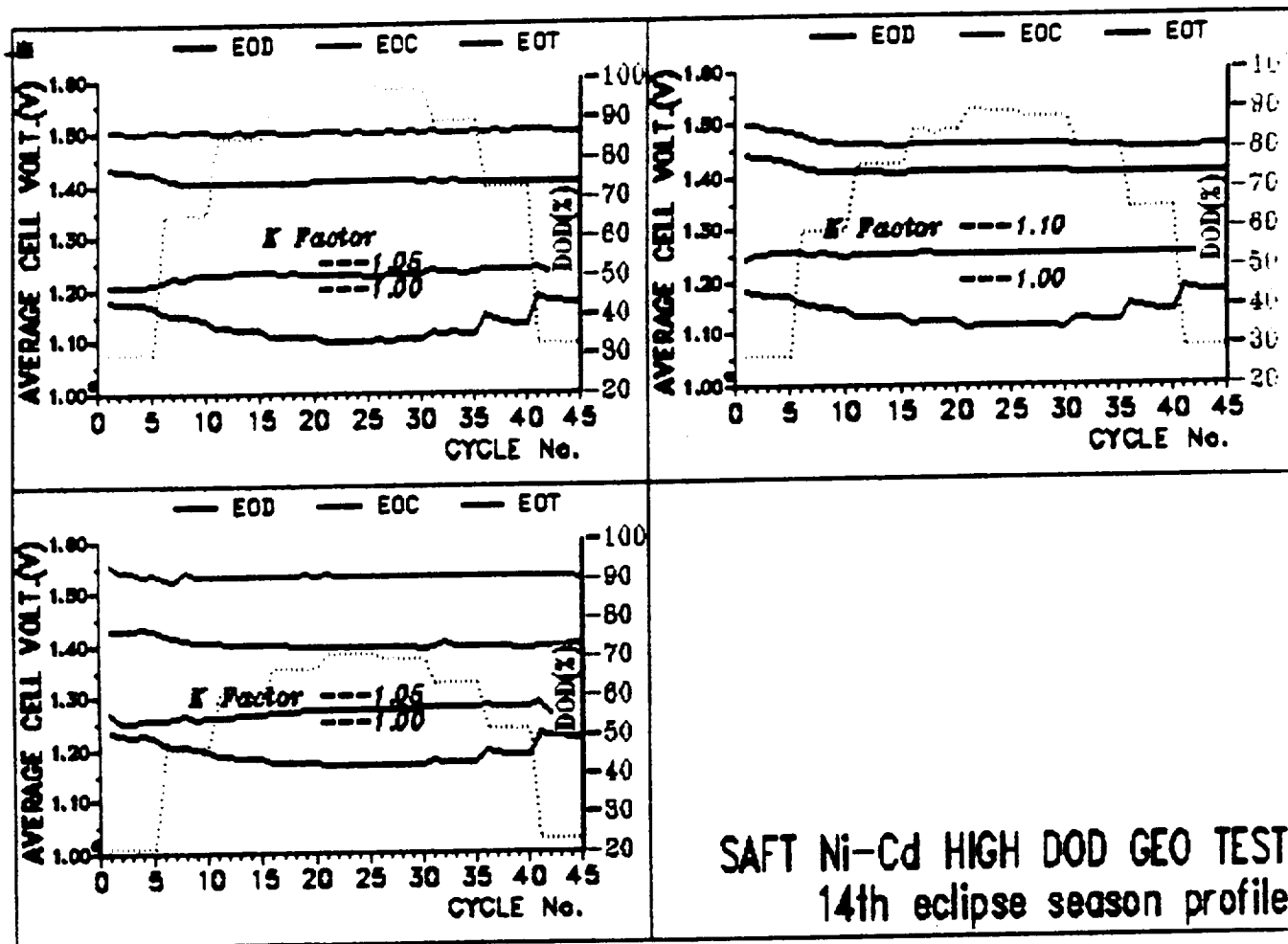
-Trickle charge at C/200 to C/100

Solstice shortened to 21 days

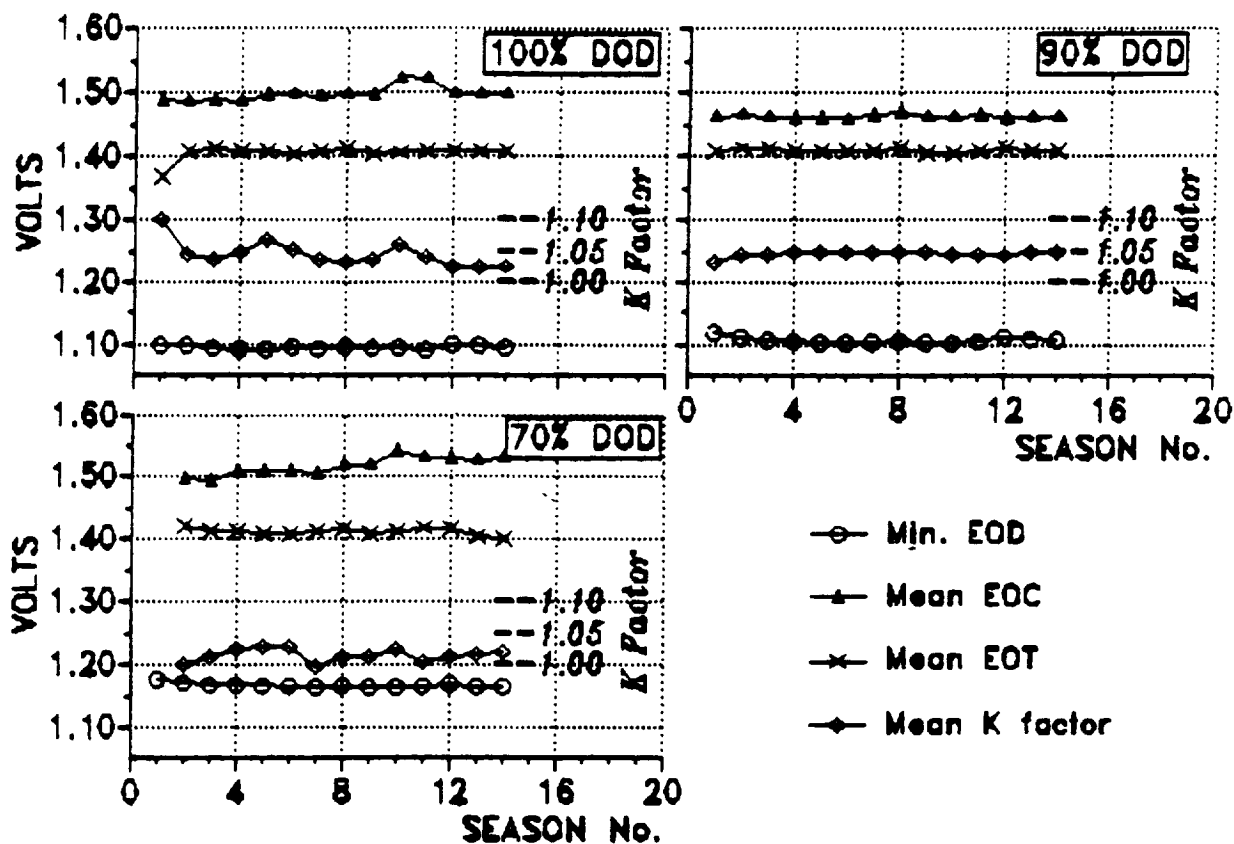
C/5 capacity check after solstice

Constant load (237.5 Ohms) reconditioning

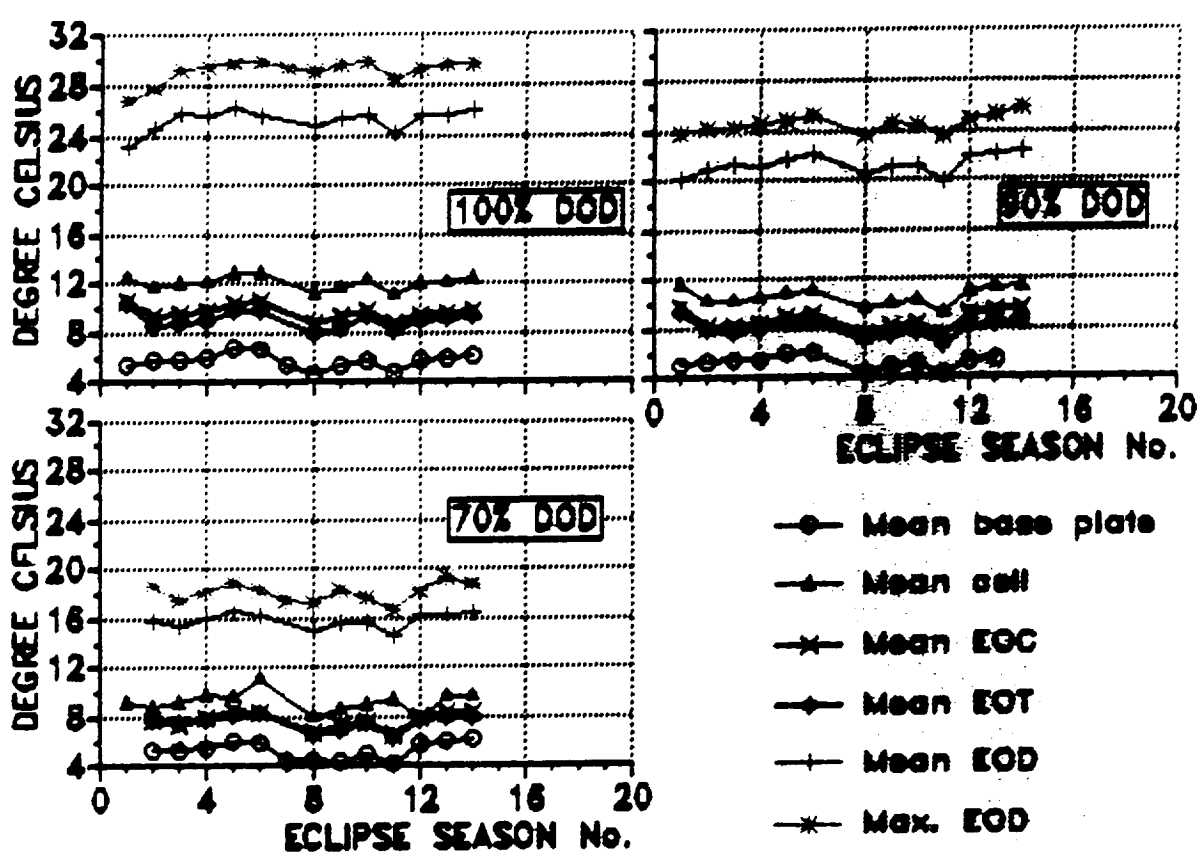
Base plate temperature : 5 Deg.C



SAFT Ni-Cd HIGH DOD GEO TEST: AVERAGE CELL VOLTAGE & K FACTOR EVOLUTION THROUGH SEASONS



SAFT NI-Cd HIGH DOD GEO TEST : BASE PLATE & CELL TEMPERATURE DURING ECLIPSE SEASONS



- NiCd HIGH DOD ACCELERATED GEO TEST

14 seasons already simulated (7 years)

Very good battery performance achieved

No capacity degradation observed

Average cell voltage (V):

1.095, 1.108, 1.165 for 100%,90%,70%DOD

No adverse effect from test acceleration

GEO NiCd at high DOD seems feasible

OTS-2 10y. REAL FLIGHT SIMULATION

Lab test to mirror OTS-2 bat. operation

Started 9/78, OTS-2 launched 5/78

OTS-2 operational for 6.5y, hib. since 5/85

28 V018S SAFT cell battery

2-14 cell halves in 2 chambers(-Y/+Y sim.

DOD max : 50% for operat., 60% for hib.

Charge C/10 to set K factor, Volt. back-up

Solstice trickle from 8h to 24h a day.

Av. Temperature through 10 years: 15 Deg.C

OTS-2
VERNAL EQUINOX 1988
DISCHARGE TIMES

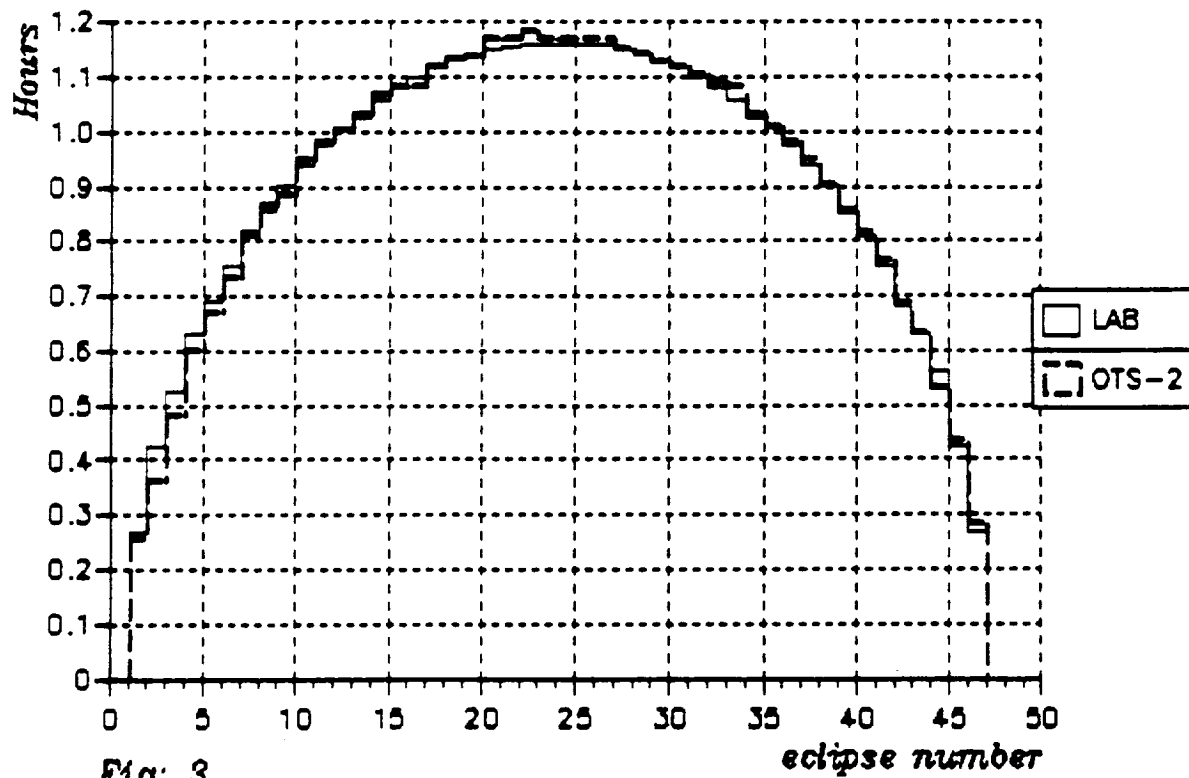


Fig: 3

OTS-2
EVOLUTION OF THE DOD OVER 10 YEARS.
MAXIMUM VALUES

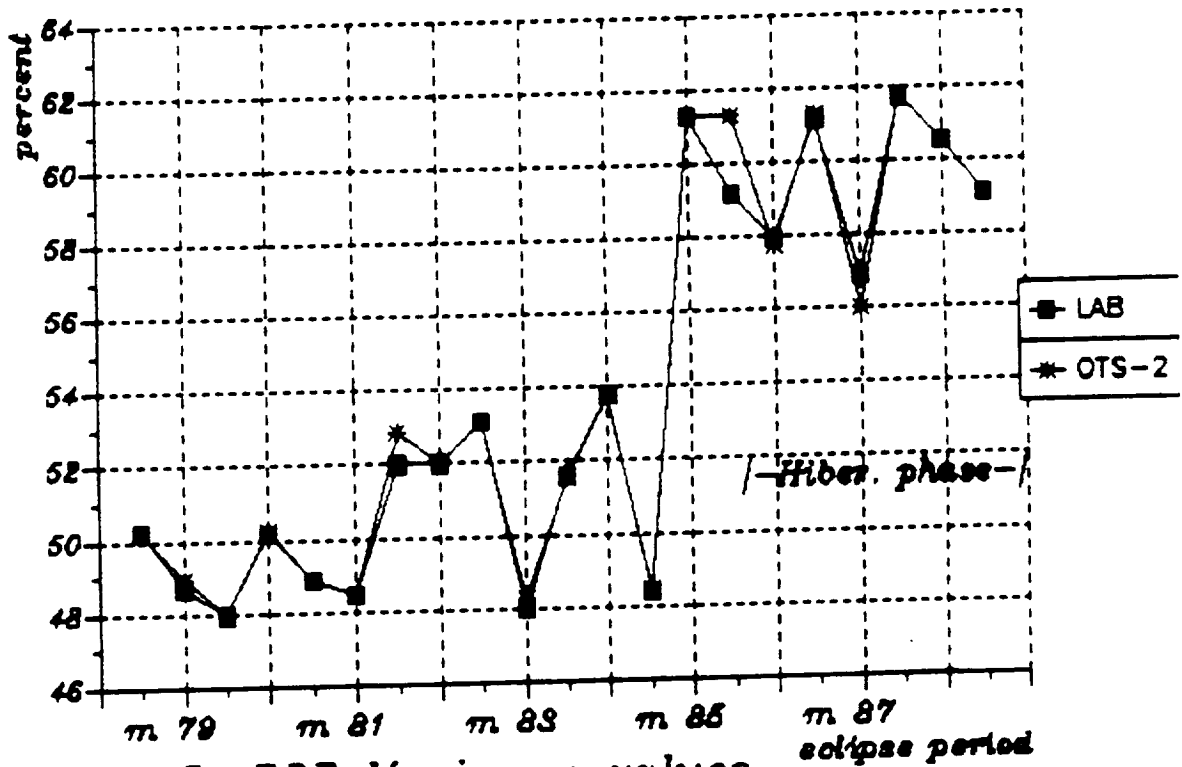
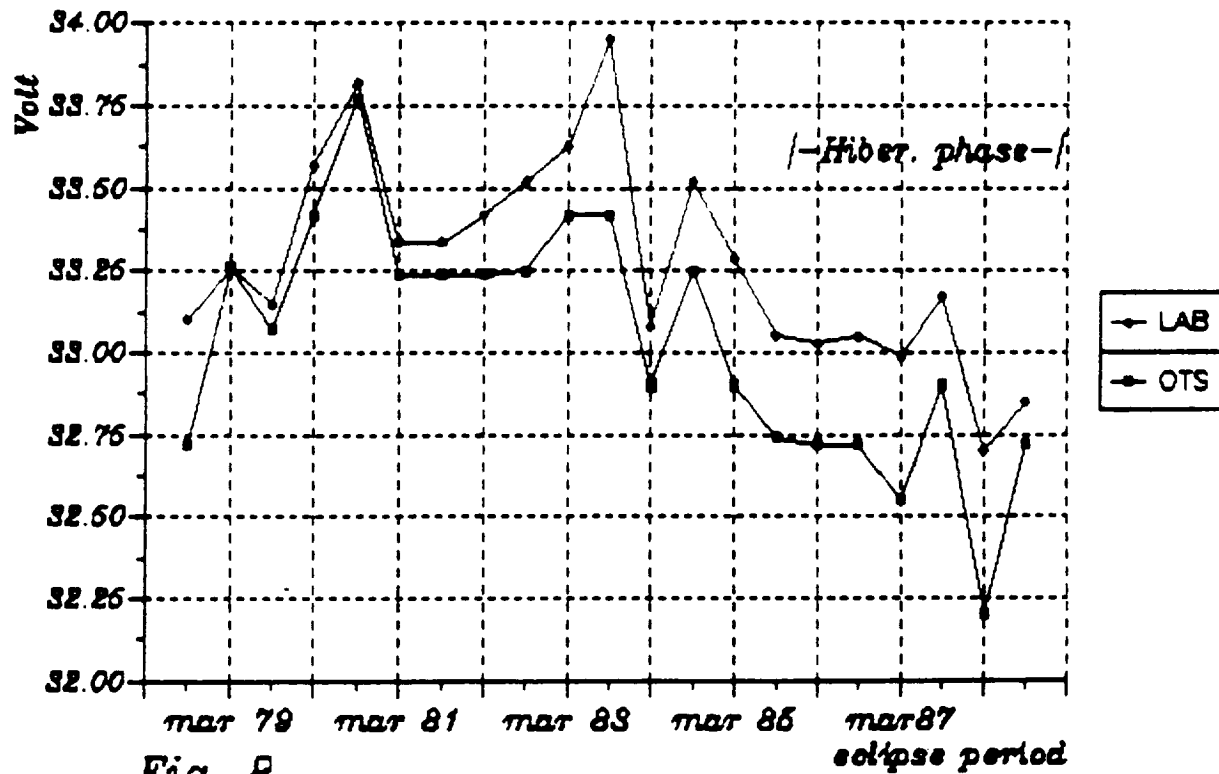


Fig: 5 DOD Maximum values

OTS-2
EVOLUTION OF THE VB AT EOD OVER 10 YEARS
MID ECLIPSE PERIOD



OTS-2 USED K-FACTORS OVER 10 YEARS MID-ECLIPSE PERIODS

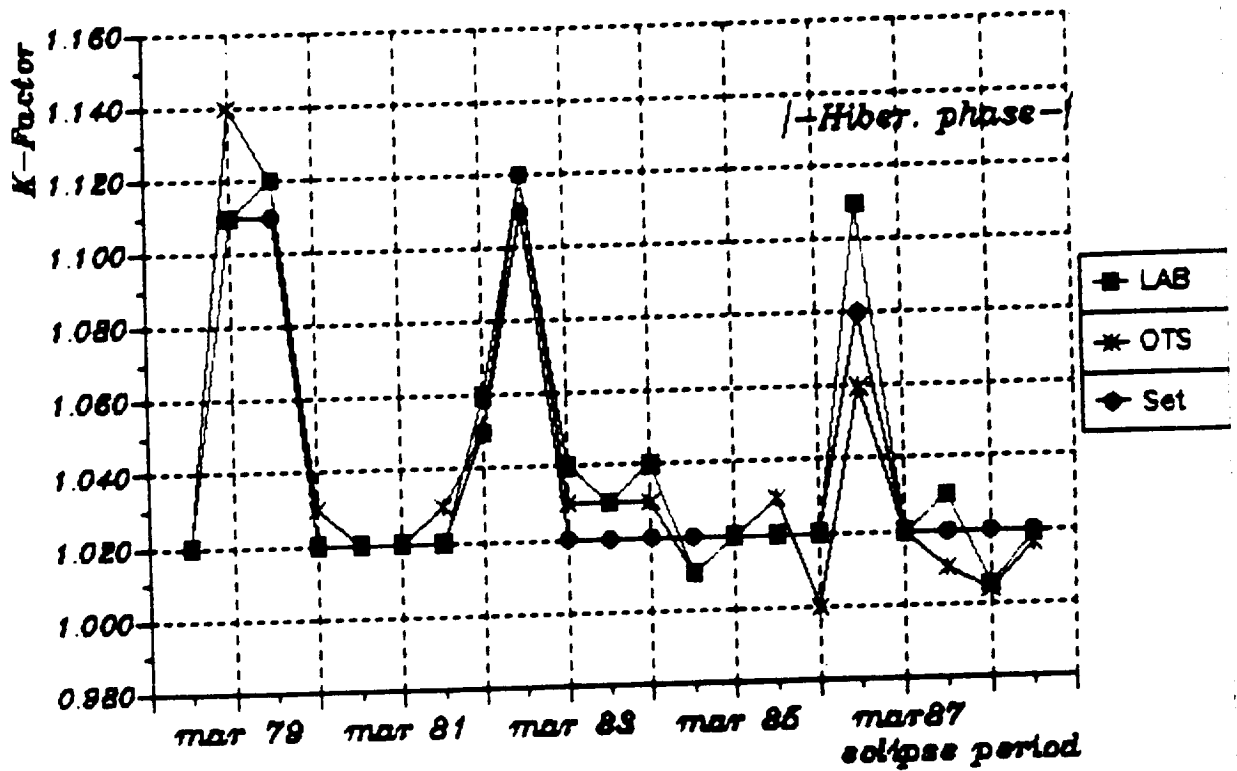


Fig. 7

OTS-2
EVOLUTION OF THE VB AT EOC, OVER 10 YEARS
MID ECLIPSE PERIOD

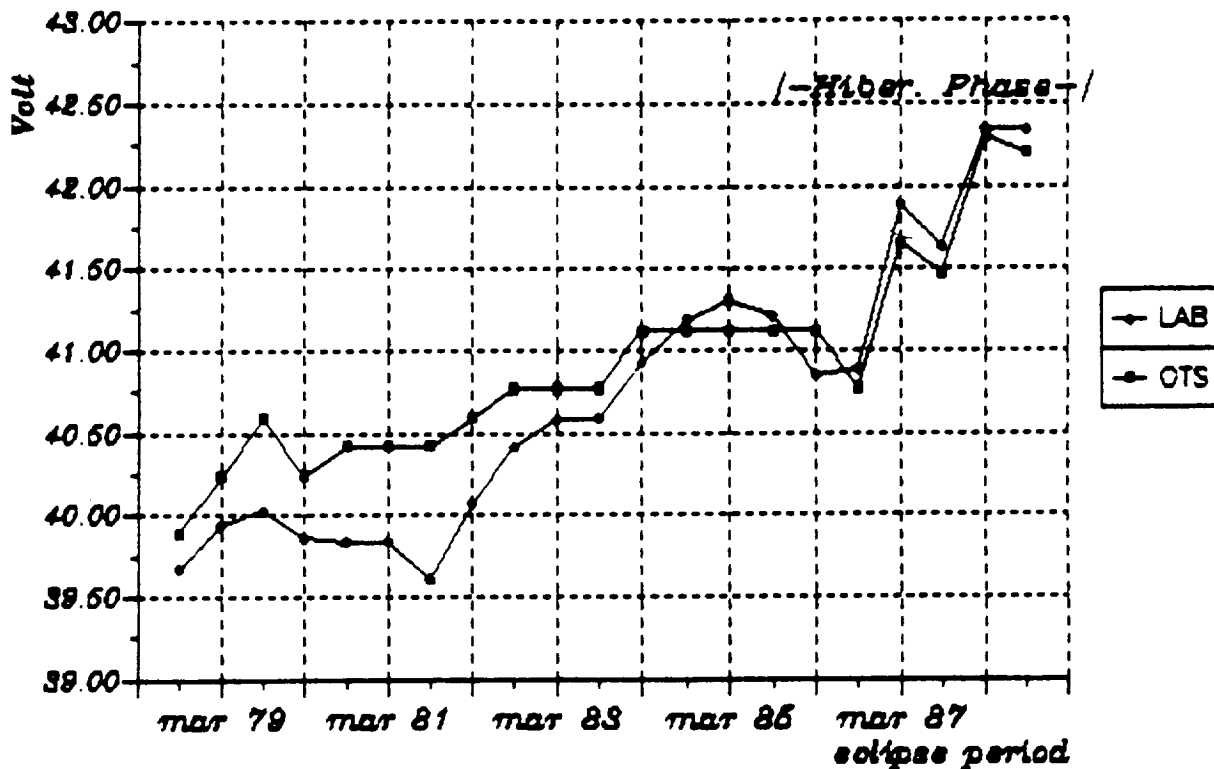


Fig. 9

OTS-2 LAB LOW RATE RECONDITIONING DATA BATTERY CAPACITIES

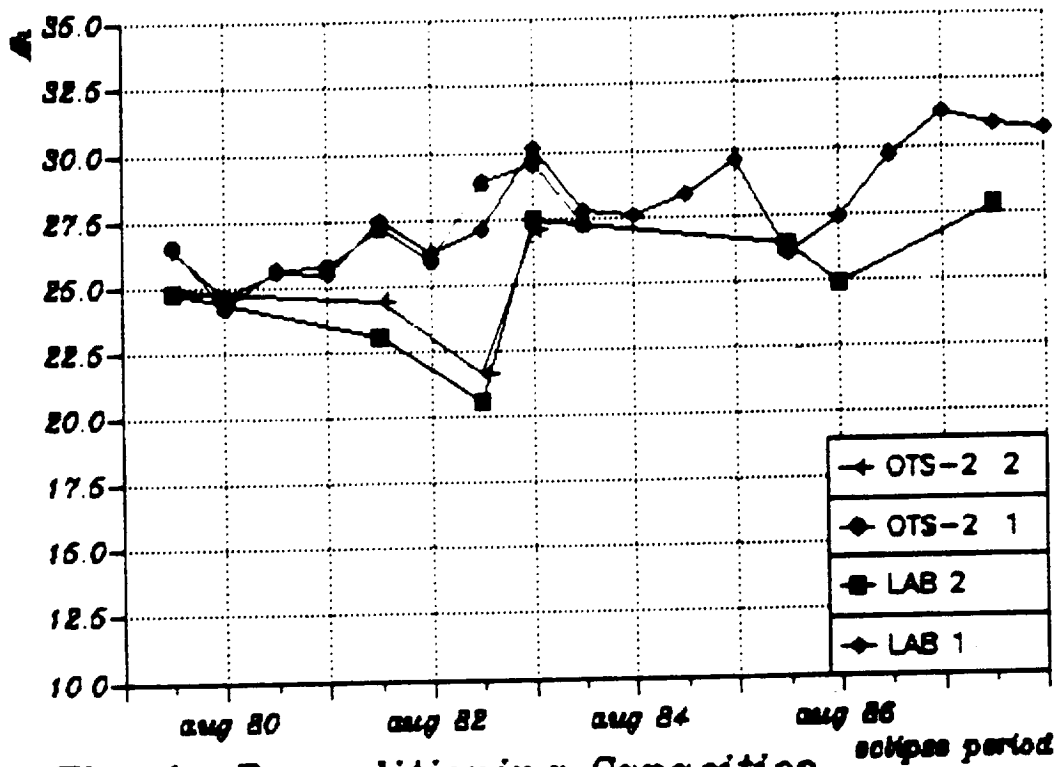


Fig. 1 Reconditioning Capacities

SAFT AEROSPACE DEPARTMENT	NOV. 1988
SAFT NICKEL-CADMIUM CELLS BEING TESTED AT THE EUROPEAN BATTERY TEST CENTER J. GOUALARD 1988 NASA/GSFC BATTERY WORKSHOP	

SAFT AEROSPACE DEPARTMENT	NOV. 1988
SAFT NICKEL-CADMIUM CELLS BEING TESTED AT THE EUROPEAN BATTERY TEST CENTER SUMMARY . SPACE PROGRAMS HISTORY FLIGHT EXPERIENCE PRISMATIC CELLS FLIGHT EXPERIENCE CURRENT PROGRAMS . GROUND TEST EXPERIENCE - GEO SYNCHRONOUS AND LOW EARTH ORBIT SIMULATION . CELL DESIGN AND MANUFACTURING . CELL CHARACTERISTICS AND PERFORMANCES - QUALIFICATION CELLS - ESA-BTC TEST GEOSYNCHRONOUS ORBIT - ESA-BTC TEST LOW EARTH ORBIT . CONCLUSION	

SAFT AEROSPACE DEPARTMENT			NOV. 1988	
IN FLIGHT EXPERIENCE				
YEAR OF LAUNCH	NUMBER OF SATELLITES	Ah RATING	SPACE PROGRAM	
1965 - 1969 1970 - 1979	3 17	3.5Ah 2 TO 18Ah	DIAPASON - DIADEMES 1 - 2 PEOPLE - D2A - ESRO IV ANS - INTASAT - SYMPHONY A - B STARLETTE - CASTOR POLLUX SRET - COS.B - D2B SIRIO 1 METEOSAT 1 - OTS 2 ARIEL	
1980 - 1985	14	2 to 18Ah	ROHINI 1 - 2 - 3 - METEOSAT 2-APPLE - MARECS A IRAS EXOSAT - ECS 1 - ECS 2 TELECOM 1A - 1B AMPT.E. MARECS B2	
1986 - 1987 1988	2 6 — 42	24Ah 40Ah 24Ah 18Ah 7Ah	SPOT 1 - ECS 4 IRS 1 - TELECOM 1C ECS 5 IDF1 METEOSAT P2-X-	

SAFT AEROSPACE DEPARTMENT		NOV. 1988
IN FLIGHT EXPERIENCE <u>PRISMATIC CELLS</u> . CAPACITY : 7Ah TO 40Ah . 20 SATELLITES . GEO SYNCHRONOUS ORBIT : 17 SATELLITES (13 OPERATING) 18Ah - OTS.2 - LAUNCHED MAY 1978 (OPERATING 20 ECLIPSES SEASONS 60% DOD) . LOW EARTH ORBIT (3 SATELLITES) 24 Ah SPOT 1 LAUNCHED FEB 1986 (OPERATING) 40 Ah IRS 1 LAUNCHED MARCH 1988 (OPERATING) . 18 MILLIONS/CELLS/HOURS OF OPERATION		

SAFT AEROSPACE DEPARTMENT

NOV. 1988

GROUND TEST EXPERIENCE

. GEOSYNCHRONOUS ORBIT SIMULATION

. REAL TIME

26Ah - DOD 60%
 21Ah DOD 60%
 18Ah DOD 60%

. SIMULATION

CYCLE DURATION

6h TO 24 HOURS

ECLIPSE DURATION

REAL - STEPS - CONSTANT (MAX)

DEPTH OF DISCHARGE

50 TO 100%

Ah RATING

7Ah TO 40Ah

TEMPERATURE

0° TO 25° CENTIGRADE

. ~350 CELLS

. 13 MILLIONS/CELLS/HOURS OF OPERATION

SAFT AEROSPACE DEPARTMENT		NOV. 1988
GROUND TEST EXPERIENCE		
. LOW EARTH ORBIT SIMULATION (100 MINUTES)		
. Ah RATING	18Ah TO 40Ah	
. DOD	10 TO 50%	
. TEMPERATURE	0° TO 30° CENTIGRADE	
. 340 CELLS		
7 MILLIONS/CELLS/HOURS OF OPERATION		

SAFT AEROSPACE DEPARTMENT		NOV. 1988
CURRENT PROGRAMS		
Ah RATING	SPACE PROGRAM	CUSTOMER
7	METEOSAT -2-3-4	ETCA - (EUMETSAT)
7	ARSENE	CNES - RADIO-AMATEUR
10	HIPPARCOS	BRITISH AEROSPACE (ESA)
10	Y	DORNIER
18	TELE-X.	DORNIER
18	TDF 2	DORNIER (DGT)
18	ISO	AEROSPATIALE (ESA)
24	OLYMPUS	BRITISH AEROSPACE (ESA)
24	ERS 1	AEROSPATIALE (ESA)
24	SPOT-2-3	AEROSPATIALE (CNES)
24	ROSAT	DORNIER
40	EURECA	A E G (ESA)
40	IRS 2	INDIAN RESEARCH ORGANISATION
40	SPOT 4/HELLIOS	MATRA (CNES)

SAFT AEROSPACE DEPARTMENT**NOV. 1988**

NI-CD CELL DESIGN - VDS.A

NOMINAL CAPACITY RANGE 10-26Ah

ORIGINAL DESIGN 1970

QUALIFIED - ESA AND CNES 1971 - 1972

PLATES

POSITIVE	NEGATIVE
12	13
80%	84.2%
0,76mm	0,89mm
13,2 g/dm ²	17.5 g/dm ²

NUMBER

SINTER POROSITY
THICKNESS

LOADING

CAPACITY RATIO

THEORETICAL

MEASURED

1, 80
1.55 - 1.80ELECTRODE SPACING

0.26mm

SEPARATOR

NYLON

ELECTROLYTE

KOH - 31%

SAFT AEROSPACE DEPARTMENT**NOV. 1988**

NICD CELL DESIGN VOS.A

NOMINAL CAPACITY RANGE
QUALIFIED BY ESA

30-50Ah
40Ah (1984)

PLATES

NUMBER
SINTER POROSITY
THICKNESS
LOADING

POSITIVE	NEGATIVE
13	14
80%	84,2%
0,79mm	0,92mm
13,8 g/dm ²	18 g/dm ²

CAPACITY RATIO

THEORETICAL
MEASURED

1,80
1,55 - 1,80

ELECTRODE SPACING

0.26mm

SEPARATOR

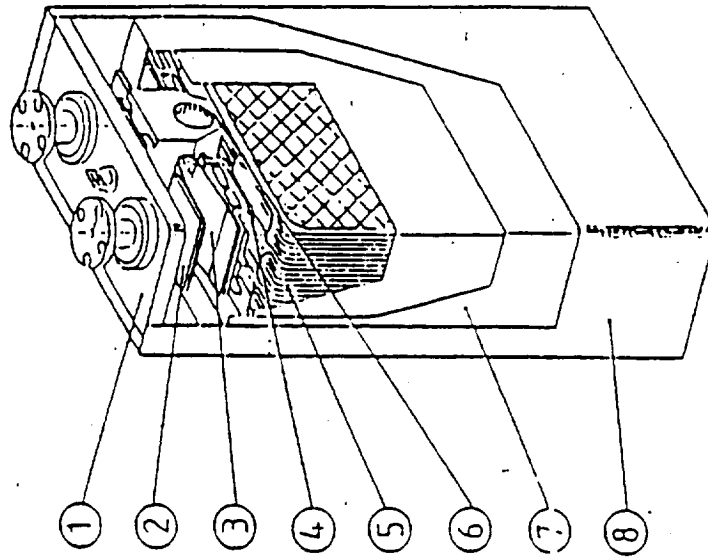
NYLON

ELECTROLYTE

KOH - 31%

HIGH CAPACITY
VO S A

- 1 COVER WITH TERMINALS
- 2 TERMINAL END
- 3 FLEXIBLE CONNECTIONS TIG WELDED ON THE
TERMINAL END AND THE COMB
- 4 COMB
- 5 GROUPS OF ELECTRODE TABS INSERTED IN THE SLOTS
OF THE COMB AND TIG WELDED
- 6 CENTRAL BLOCKING INSERTED BETWEEN THE TOP OF THE
STACK AND THE COVER
- 7 INSULATING SHEET
- 8 CASE



SAFT AEROSPACE DEPARTMENT

NOV. 1988

NICKEL-CADMIUM CELL DESIGN VOS-B
 NOMINAL CAPACITY RANGE 10-30 Ah
 DESIGN 1985

PLATE

<u>POSITIVE</u>	<u>NEGATIVE</u>
12 80 % 0.79 mm 15 g dm ²	13 84.2 % 0.92 mm 19.4 g dm ²

NUMBER
 SINTER POROSITY
 THICKNESS
 LOADING

CAPACITY RATIO

THEORETICAL
 MEASURED

1.78
 1.55 TO 1.70

ELECTRODE SPACING

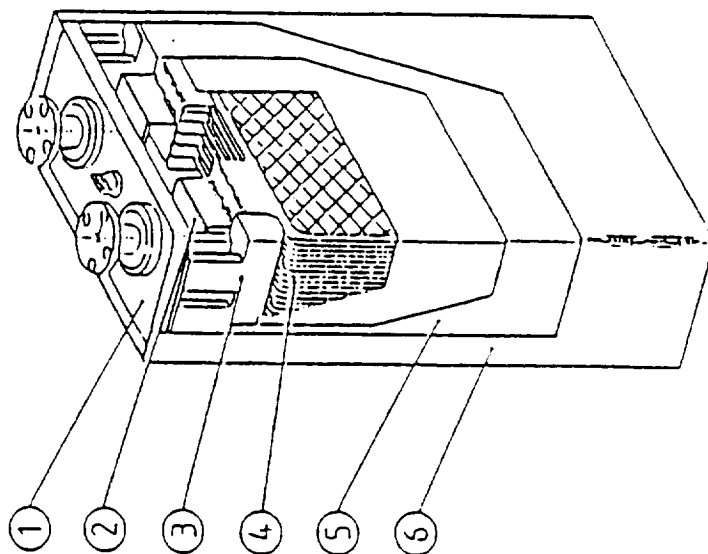
0.23 mm

SAFT AEROSPACE DEPARTMENT

NOV. 1988

MEDIUM AND HIGH CAPACITY

VO S B



COVER WITH TERMINALS

TERMINAL BOTTOM

LATERAL BLOCKING OF THE STACK

GROUPS OF ELECTRODE TABS TIG WELDED ON EACH SIDE OF THE TERMINAL BOTTOM

INSULATING SHEET

CASE

1

2

3

4

5

6

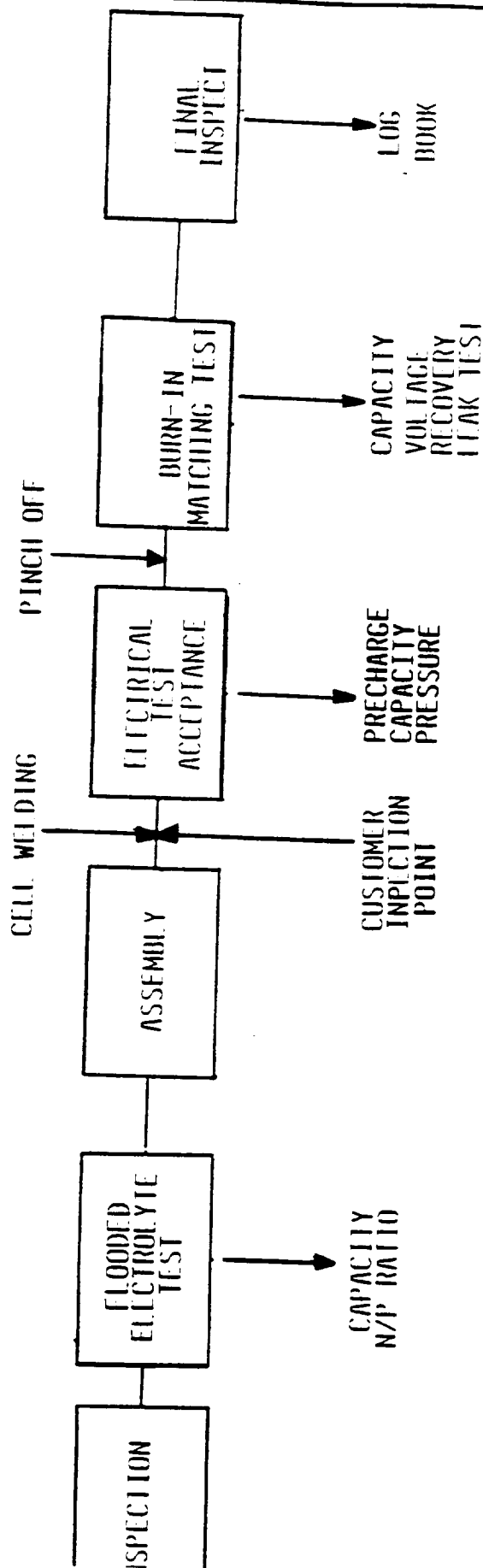
SAFT AEROSPACE DEPARTMENT

NOV. 1988

MANUFACTURING AND QUALITY CONTROL

PROCESS FLOW CHART

V10R



NOV. 1988

SAFT AEROSPACE DEPARTMENT

**QUALIFICATION - EVALUATION
CELL CHARACTERISTICS**

NAME PLATE CAPACITY (Ah)	AGENCY CUSTOMER	CELL MANUFACTURING	FLOODED ELECTROLYTE TEST (Ah)		CAPACITY ACCEPTANCE (Ah)	CAPACITY AFTER QUALIF TEST (Ah)
			+	-		
18	ESA (HSD)	06/1975	22.7	41.4	22.3	22.6
24	ESA	1971	28.5	54.7	27.8	28.6
40	ESA	06/1984	48.3	77.3	49.2	51.1
20B	CNES	09/1986	24.8	38.5	24.5	25.3

SAFT AEROSPACE DEPARTMENT

NOV. 1988

LOW EARTH ORBIT TEST
AT ESA - BT CENTER

CELLS CHARACTERISTICS

NAME PLATE CAPACITY	TEST	CELL MANUFACTURE	FLOODED ELECTROLYTE TEST (Ah)		CAPACITY ACCEPTANCE (Ah)	CAPACITY BURN IN (Ah)	TEST STATUS		
			+	-			DOD	CYCLES	CAPACITY (Ah)
24	x80	11-1978	30,2	59	29,4	N.A	22%	29000	N.A
24	ELAN	11-1983	29,3	53,7	30,5	27,4	10 to 40%	15000 to 17000	27.28 (C/7)
40	ELAN	07.1985	47,7	88,7	48,6	49,5	10 to 30%	10000	49.3-50.4 (C/3)
208	ELAN	09.1986	24,8	38,5	24,5	N.A	30%	6000	N.A

SAFT AEROSPACE DEPARTMENT

NOV. 1988

GEO SYNCHRONOUS ORBIT TEST AT USA BATTERY TEST CENTER CELLS CHARACTERISTICS

NAME PLATE CAPACITY	TEST	CELL MANUFACTURING	FLOODED ELECTROLYTE TEST		CAPACITY ACCEPTANCE	CAPACITY BURN-IN	TEST STATUS		
			+	-			DOD	ECLIPSES SEASONS	CAPACITY
18	OIS SIMULATION	04/1977	23.3	40.9	23.1	NA	57 %	21	23 Ah (C/2)
18	HIGH DOD GEO TEST (70 %)	03/1978	23.1	41.6	22.3	22	70 %	14	23.2 Ah (C/5)
18	LCS (90 %)	06/1981	22.1	40.2	21.5	22.15	90 %	14	23.5 Ah (C/5)
18	LCS (100 %)	03/1983	23.05	40.5	21.9	22.7	100 %	14	24 Ah (C/5)
21	MARECS SIMULATION	07/1980	27.5	51.4	25.9	NA	56 %	27	26.9 Ah (C/2)

SAFT AEROSPACE DEPARTMENT

NOV. 1988

EVALUATION TEST AT NMSC - CRANE

CELLS CHARACTERISTICS

NAME PLATE CAPACITY (Ah)	CELL MANUFACTURING	FLOODED ELECTROLYTE TEST (Ah)		CAPACITY ACCEPTANCE (Ah)	CAPACITY (Ah) RECONDITIONING JUNE 1988
		+	-		
24	06.1985	29.2	54.3	29.6	29.9
	04.1986	30.4	54.7	29.9	29.5
40	12.1985	50.1	90.1	49.1	50.3
20(B)	09.1986	24.8	38.5	24.5	23.9

C O N C L U S I O N

- . CELL DESIGN-PERFORMANCES QUALIFIED BY THE AGENCIES IN THE EARLY 70",
- . PERMANENT EVALUATION TESTS MAINTAINED SINCE 1975,
- . BASIC MANUFACTURING PROCESS AND COMPONENTS UNCHANGED :

- . SINTERED NICKEL
- . LOADING
- . SEPARATOR
- . ELECTROLYTE

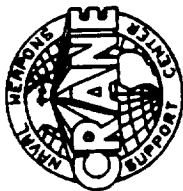
.IMPROVEMENTS INTRODUCED (OPTIONS)

- . STACK TO COVER CONNECTION (RIGID/FLEXIBLE) 1978
NO IMPACT ON CYCLE LIFE
- . REDUCED ELECTRODE SPACING 1985 (B TECHNOLOGY) BEEING EVALUATED
NO DIFFERENCE AFTER 1/YEAR LEO 30 % DOD

APL LIFE TEST PROGRAM ON 2505/2536 SEPARATOR

(NOT SUBMITTED)

L. GOLIASZEWSKI, APL



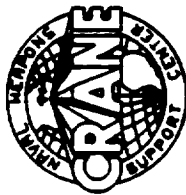
November 1-3, 1988

AIR FORCE/NAVY SEPARATOR QUALIFICATION PROGRAM FOR AEROSPACE CELLS

**P. J. DALTON AND S. W. HALL
NAVAL WEAPONS SUPPORT CENTER
CRANE, INDIANA**

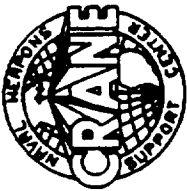
**W. C. HWANG AND P. A. MALACHESKY
THE AEROSPACE CORPORATION
EL SEGUNDO, CALIFORNIA**

**NASA GODDARD
2 NOV 1988**



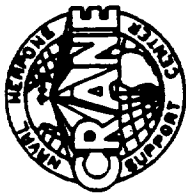
OUTLINE

- PURPOSE OF TEST PROGRAM
 - QUALIFY CELLS THAT USE PELLON 2536 SEPARATOR MATERIAL
 - CONDUCT BOTH REAL TIME LEO AND COMPRESSED TIME GEO LIFE TESTING
- BACKGROUND
- LEO TEST RESULTS
 - TEST CONDITIONS AND CELL FAILURE ANALYSIS
 - PERFORMANCE TRENDS AND FAILURE ANALYSIS
- GEO TEST RESULTS
- CONCLUSIONS



BACKGROUND

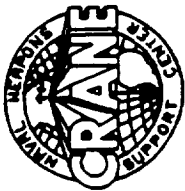
-
- **MANUFACTURE OF AEROSPACE QUALIFIED PELLON 2505 ML DISCONTINUED IN 1976**
 - **GATES ENERGY PRODUCTS (FORMALLY GENERAL ELECTRIC BATTERY BUSINESS DEPARTMENT) SELECTED PELLON 2536 AS REPLACEMENT**
 - **CONDUCT JOINT AIR FORCE/NAVY SPONSORED PROGRAM**
 - **GENERAL QUALIFICATION OF CELLS MADE WITH 2536**
 - **QUALIFICATION BASED ON SIMILARITY WITH CELLS USING 2505**
 - **TEST CELLS IDENTICAL EXCEPT FOR SEPARATOR**
 - **IDENTICAL TEST PROFILE AND CONDITIONS FOR CELLS WITH PELLON 2505 AND 2536**
 - **THREE DIFFERENT CELL TYPES**
 - **EXISTING MCD'S FROM 3 DIFFERENT PROGRAMS/CONTRACTORS**
 - **GATES STATE-OF-THE-ART IN 1984**
 - **TEST PROGRAM STARTED IN 1985**
 - **PREVIOUS REPORTS AT GSFC WORKSHOPS AND IECEC**



CELL BUILD INFORMATION

	26.5 AH	34 AH	35 AH*	50 AH**
POSITIVE PLATE				
TREATMENT	PQ	PQ	PQ	NO PQ
SINTER DATE	1/84	1/83	4/84	10,11/84
SINTER WT (g/dm ²)	10.90	10.03,9.81	9.77	10.87,10.35
LOADING (g/dm ²)	12.61	12.62,11.90	13.02	13.55,12.91
NEGATIVE PLATE				
TREATMENT	TEFLON	SILVER	SILVER	SILVER
SINTER DATE	1/84	1/83	3/84	10,11/84
SINTER WT (g/dm ²)	10.60	9.99,10.20	10.46	10.31,10.22,NA
LOADING (g/dm ²)	15.79	15.53,15.70	15.58	15.53,15.98,15.21
ELECTROLYTE				
FILL DATE	3/85	1/85	85	4/85
FILL 2505 (m)	81.0	102.0	85.0	124.5
FILL 2536 (m)	79.5	100.0	82.0	120.0

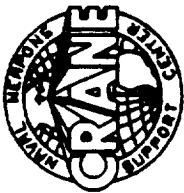
* NOT ACCEPTED FOR TEST PROGRAM ** LIGHTWEIGHT DESIGN



TEST MATRIX

SEPARATOR TYPE				2505 ML			2536		
ORBIT	DOD % ACTUAL	CHARGE CONTROL	TEST TEMP °C	50AH	34AH	26.5AH	50AH	34AH	26.5AH
LEO	25	V/T TAP	0		5	5	5	5	5
LEO	40	V/T TAP	20		10	9	10	10	9
GEO	75	V/T TAP	0	5			5		
GEO	75	V/T TAP	20	10			10		

NOTE : 30 35 AH CELLS FAILED ACCEPTANCE TESTS



LEO TESTS

- **ACCEPTANCE TESTS**

- **LIFE CYCLE TESTS (INITIAL)**
- **SIDE BY SIDE COMPARISON OF CELLS WITH PELLON 2505 AND 2536 SEPARATOR MATERIAL**
- **COMMON LIFE CYCLE TEST ANOMALY**
 - **VOLTAGE DISPERSION**
 - **MOST PREDOMINANT AT EOC**
 - **FIRST AND IN GREATER PERCENTAGE IN 2536 PACKS**
- **ATTEMPTS TO CORRECT PROBLEM ONLY SHORT TERM EFFECTS**
 - **RECONDITIONING**
 - **V/T CHARGE CONTROL VARIATIONS**
 - **CHARGE/DISCHARGE CURRENT RATE VARIATIONS**
 - **MANUFACTURER SUGGESTED PACK STABILIZATION SEQUENCE**

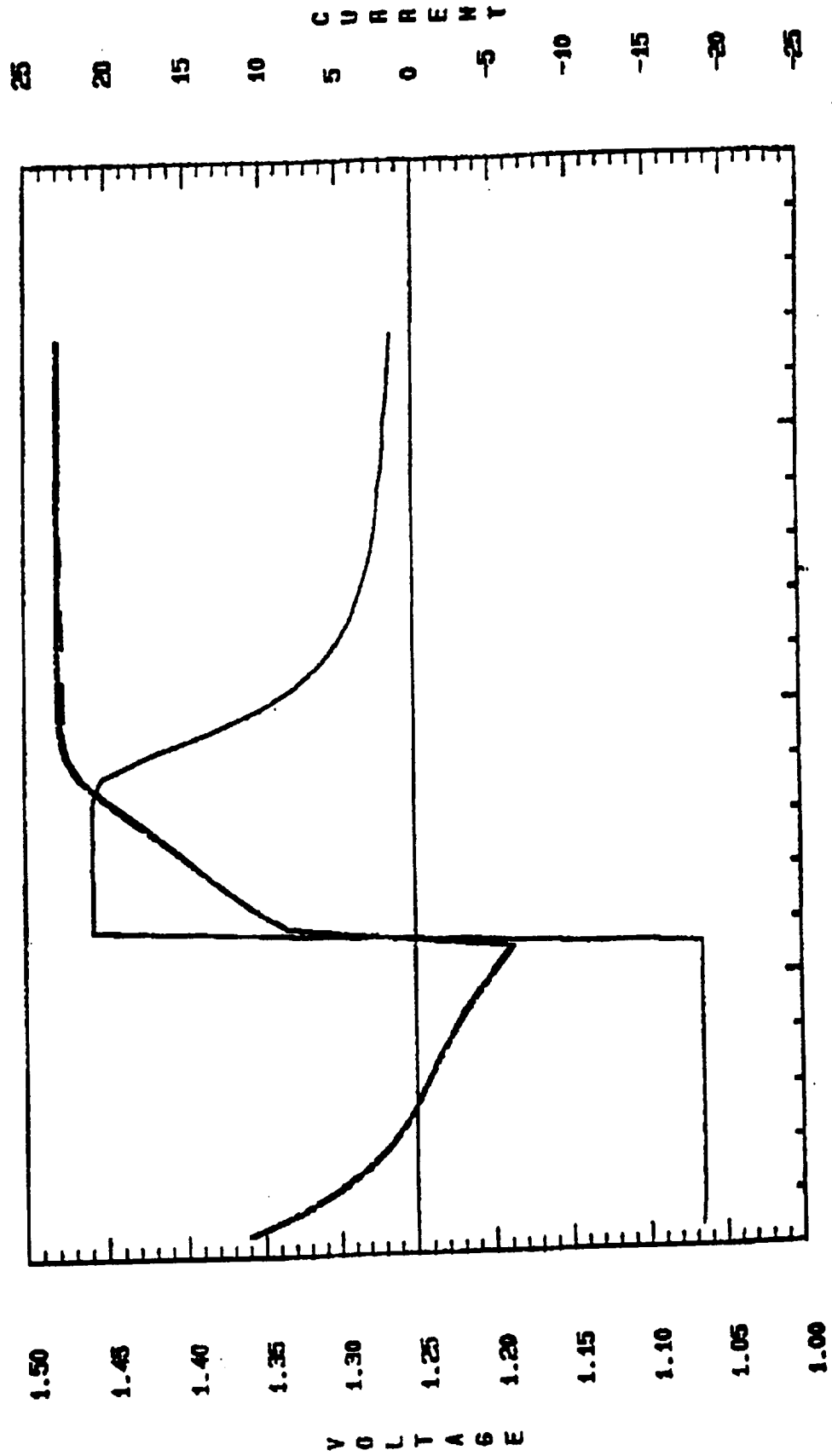
PAGE 6

RECENTIFICATION-LIFE CYCLING

Pack: 3348 Manuf: GE Cycle 1016
 Orbit: LED Temp (C): 0 DOD (X): 25 Vt. Level: 6
 Voltage Limit (V/c): 1.480 Time to Vt. Limit (Hrs):
 Discharge (amp/Hrs): 18.5/1.55 Charge (amp/Hrs): 20.8/1.12
 AH out: 10.368 AH in: 10.666 C/D RATIO: 1.029 EOC (H): 1.94
 Cell Design: New Pelton

Key:

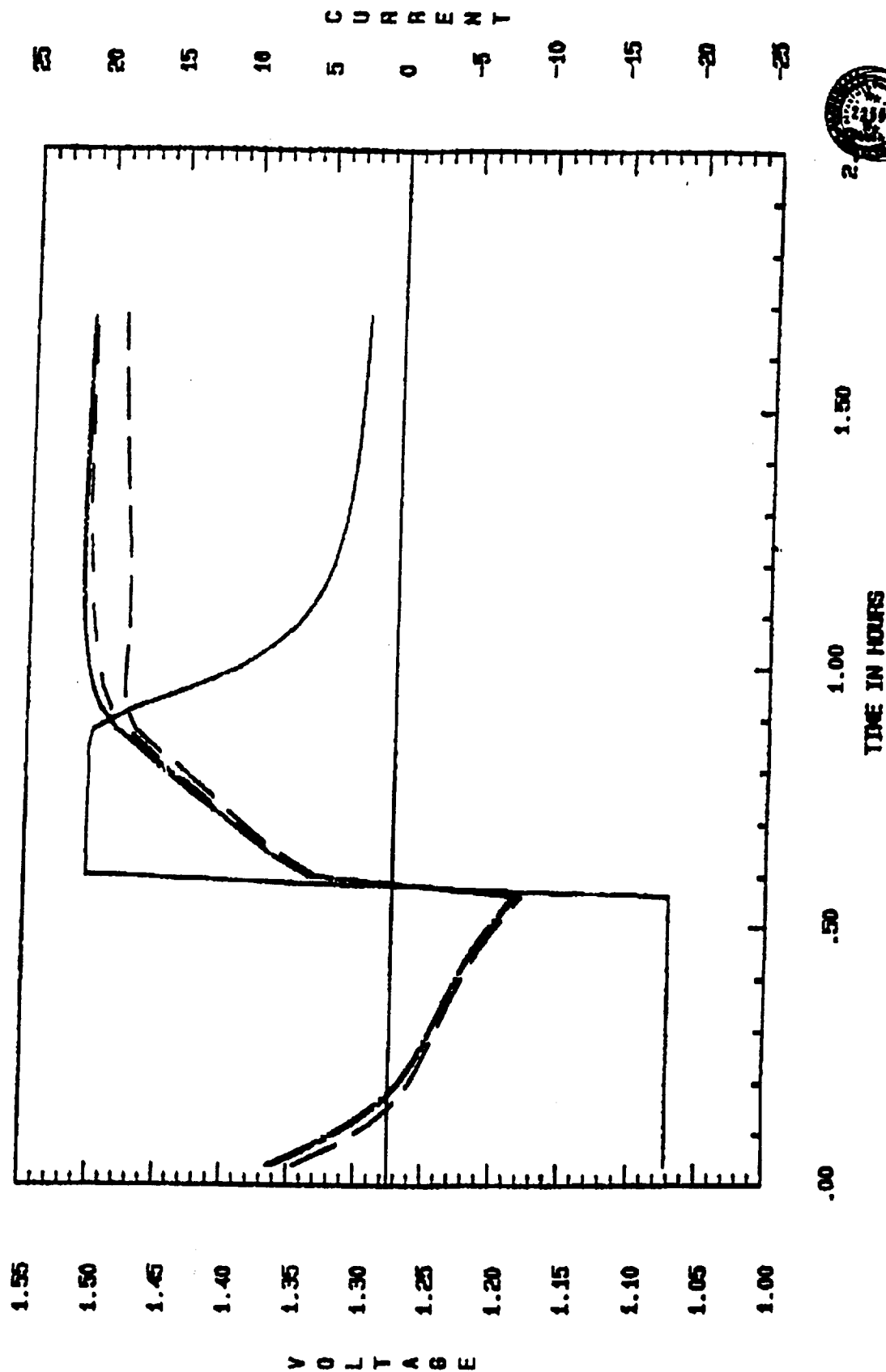
_____	Current
_____	Volt: Cell 1
_____	Volt: Cell 2
_____	Volt: Cell 3
_____	Volt: Cell 4
_____	Volt: Cell 5



RECHARGE/LIFE CYCLING

Pack: 3348 Manuf: BE Cycle: 1407
 Orbit: LED Temp (C): 0 DOD (X): 25 Vt. Level: 6
 Voltage Limit (V/C): 1.480 Time to Vt. Limit (hrs):
 Discharge (amp/hrs): 18.5/.56 Charge (amp/hrs): 20.8/1.12
 AH out: 10.362 AH in: 11.361 C/D RATIO: 1.096 EOC (H): 2.34
 Cell Design: New Pellon

Key: Current
 --- Volt: Cell 2
 --- Volt: Cell 3
 --- Volt: Cell 4
 --- Volt: Cell 5

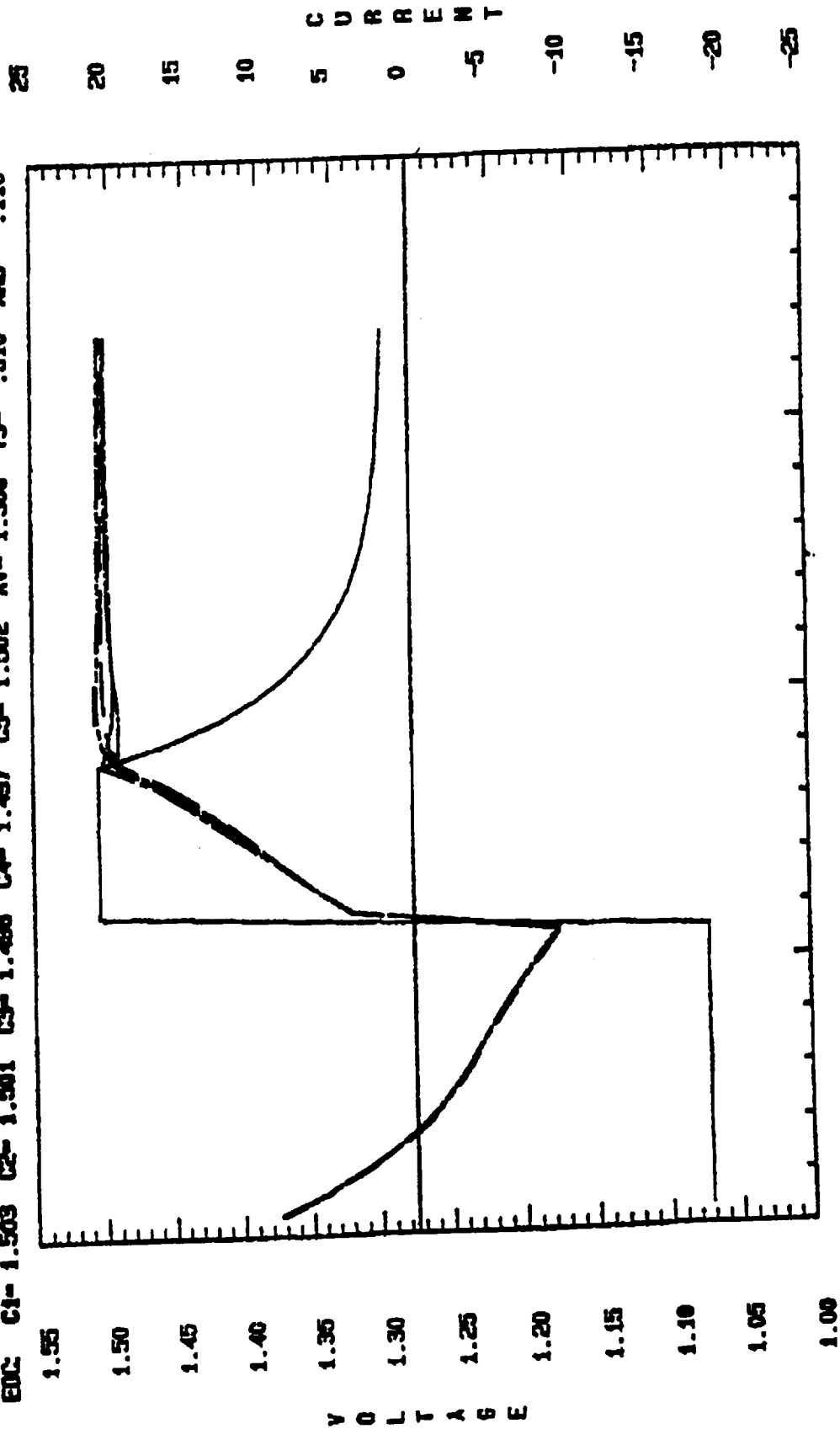


START OF CYCLE: 9/ 3/87
 Pack: 334A Manuf: 6E
 Orbit: LED Temp (C): 0
 Voltage Limit (v/c): 1.500
 Discharge (amp/hrs): 18.5/.56
 AH out: 10.368 AH in: 10.848
 Cell Design: Old Pelton

RECHARGE-LIFE CYCLING
 34 AH Cycle 5613
 DOD (X): 25 Vt. Level: 7
 Time to Vt. Limit (hrs):
 Charge (amp/hrs): 20.8/1.12
 C/D RATIO: 1.046 EOC (I): 1.70

Key:
 --- Current
 --- Volt: Cell 1
 --- Volt: Cell 2
 --- Volt: Cell 3
 --- Volt: Cell 4
 --- Volt: Cell 5

EOC C1- 1.173 C2- 1.175 C3- 1.175 C4- 1.174 C5- 1.174 AV- 1.175 T3- 2.410 ANB- -.260
 EOC C1- 1.503 C2- 1.501 C3- 1.488 C4- 1.487 C5- 1.502 AV- 1.508 T3- .510 ANB- -.110



START OF CYCLE: 10/ 8/87

Pack: 334A

Orbit: LEO

Voltage Limit (v/c): 1.500

Discharge (amp/Hr): 18.5/.56

AH out: 10.373

Cell Design: Old Pelton

RECHARGE-LIFE CYCLING

34 AH Cycle 6111

Time to Vt. Limit (Hrs): 20.8/1.12

Charge (amp/Hr): 20.8/1.12

C/D RATIO: 1.044

EDC (I): 1.86

Cell Design: Old Pelton

Key:

Current

Volt: Cell 1

Volt: Cell 2

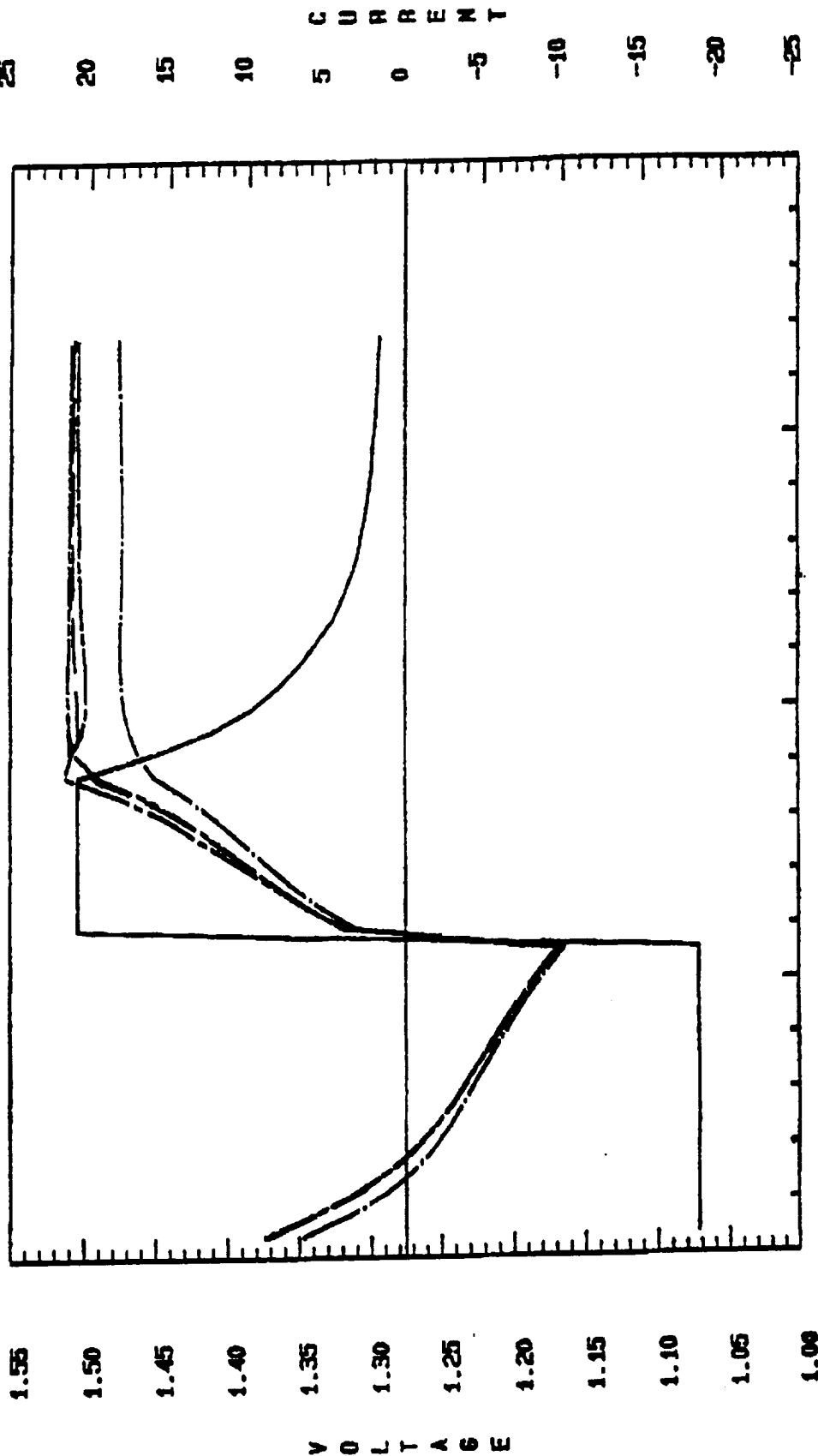
Volt: Cell 3

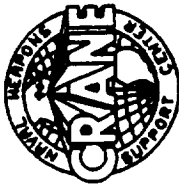
Volt: Cell 4

Volt: Cell 5

EOC: C1- 1.168 C2- 1.168 C3- 1.164 C4- 1.167 C5- 1.168 AV- 1.168 T3- .550 AHB-1.350

EOC: C1- 1.507 C2- 1.506 C3- 1.476 C4- 1.504 C5- 1.509 AV- 1.500 T3-1.170 AHB-1.300

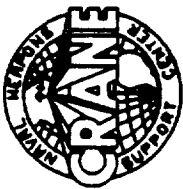




RESULTS FROM LEO TESTS

PACK ID	CAPACITY	PELLON TYPE	# CELLS	DOD	TEMP	FAILED CELLS		CYCLES TO DATE
						#	FIRST CYCLE	
326A	26.5	2505	5	25	0	1	7978	12669
326B	26.5	2536	5	25	0	4	10151	12337
326C	26.5	2505	9	40	20	3* 2	8231	12105
326D	26.5	2536	9	40	20	7* 1	9885	12334
334A	34	2505	5	25	0	1	6241	11248
334B	34	2536	5	25	0	5	4012	7929
334C	34	2505	10	40	20	0	-	9552
334D	34	2536	10	40	20	10	6095	9491
350C	LW 50	2536	5	25	0	5	4502	7243
350D	LW 50	2536	10	40	0	10	3260	6236

* CELLS CYCLING BELOW 1.00V CUT OFF



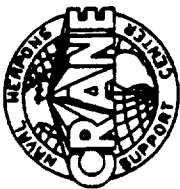
LEO TEST SUMMARY

• NEW SEPARATOR CELLS ARE PERFORMING POORER THAN OLD SEPARATOR CELLS

- EARLIER PROBLEMS AND FAILURES
- LARGER NUMBER OF FAILURES
 - BASED ON SIDE-BY-SIDE COMPARISON
 - 28* OUT OF 29 CELLS WITH 2536 REACHED 1.00V CUT OFF OR ARE REMOVED FROM CYCLING
 - 17 OUT OF 29 CELLS WITH 2505 REACHED 1.00V CUT OFF OR ARE REMOVED FROM CYCLING
- CELLS REMOVED FROM CYCLING
 - 20 OUT OF 29 CELLS WITH 2536
 - 14 OUT OF 29 CELLS WITH 2505

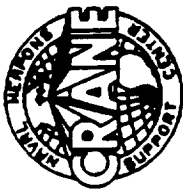
* 2536 50 AH CELLS NOT INCLUDED

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RESULTS OF DESTRUCTIVE PHYSICAL ANALYSIS (DPA)

- DPA OF 6 FAILED LEO-CYCLED CELLS (5 WITH 2536, 1 WITH 2505)
 - VISUAL OBSERVATIONS
 - LOCALIZED PROBLEMS - TOP, BETWEEN TABS
 - Cd MIGRATION
 - SEPARATOR DAMAGE FROM HEATING
 - NO EVIDENCE OF WEAKENED SEPARATOR
 - POSSIBLE FACTORS CONTRIBUTING TO FAILURE
 - ELECTROLYTE DISTRIBUTION
 - HEAT GENERATION
- DPA OF 35 AH WITH 2505- LOT 30158, ROLL RL326460
 - NO CYCLING- FAILED ACCEPTANCE TESTS
 - SYMPTOMS OF SEPARATOR OXIDATION
 - NO SEPARATOR STRENGTH
 - LOST 50% OF OVERCHARGE PROTECTION



RESULTS FROM GEO TESTS

- LIGHT WEIGHT 50 AH CELLS WITH PELLON 2536 AND 2505
 - 75% DOD (BASED ON ACTUAL CAPACITY)
 - PACKS AT 0° AND 20° C
 - USE V/T WITH TAPER CHARGE CONTROL
 - SIMULATE ECLIPSE SEASONS AND RECONDITIONING PERIODS
- NO FAILURES TO DATE FOR 30 CELLS IN COMPRESSED TIME TEST
 - CYCLING EQUAL TO 14 SIMULATED ECLIPSE SEASONS
 - 28 MONTHS OF ON LINE TESTING
- NO PROBLEMS FOR CELLS WITH PELLON 2505 OR 2536 AT 0° C
- PROBLEMS FOR 20° C CELLS (WITH PELLON 2505 AND 2536)
 - NO PQ TREATMENT OF POSITIVES CAN LEAD TO LOW CHARGE EFFICIENCY AT HIGHER TEMPERATURES
 - HIGH CHARGE/DISCHARGE RATIO NEEDED (>2.5) TO MAINTAIN CELLS ABOVE 1.1 VOLT AVERAGE
 - LOWER V/T LEVELS WOULD LEAD TO EOD VOLTAGES BELOW 1.0 VOLTS

START OF SHADOW: 5/17/88

RECERTIFICATION

Pack: 250A Manuf: GE 50 AH

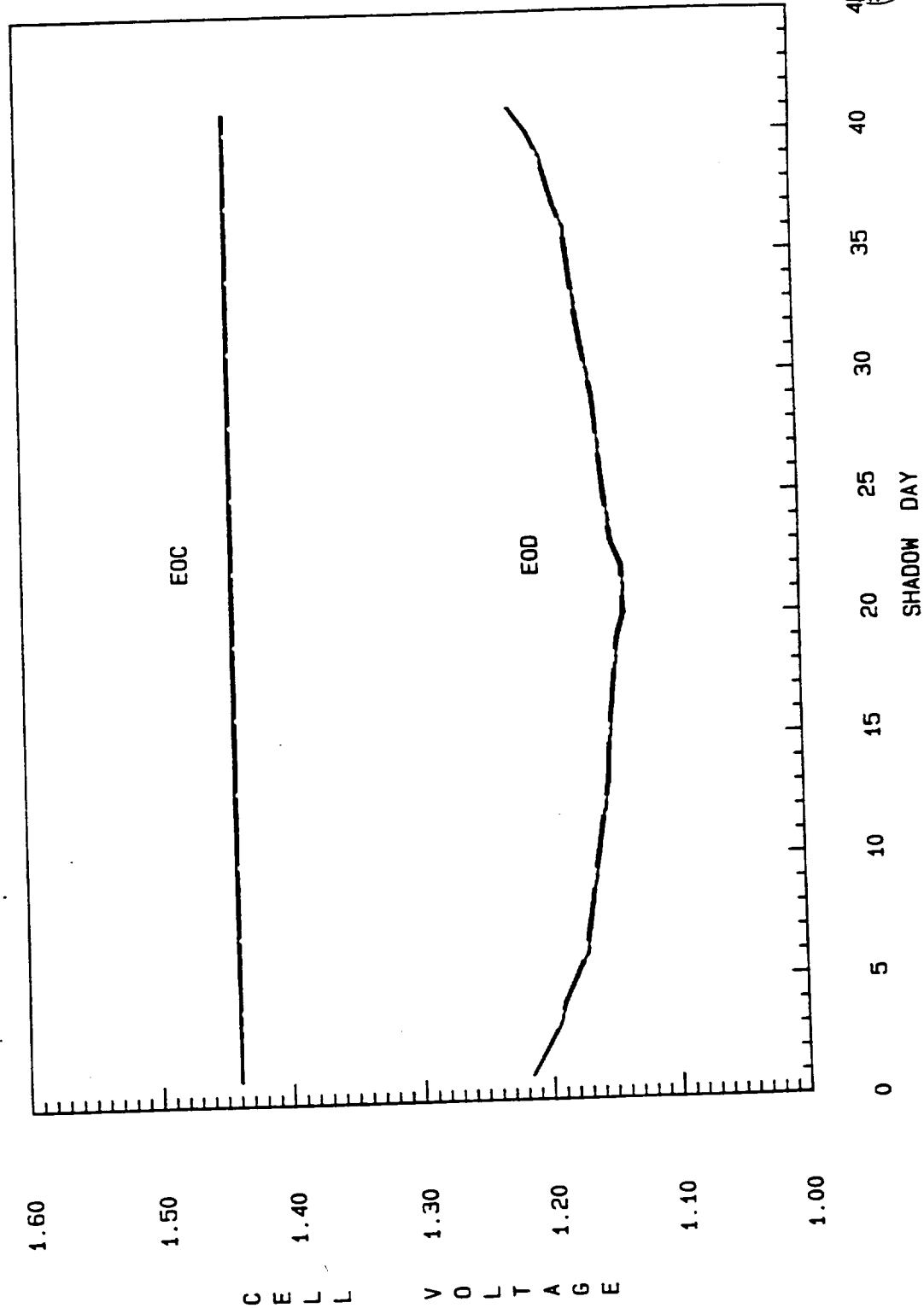
Shadow #12 - Cell Voltage vs Day

Cycle: 551 to 591 Temp (C): 0 DOD(%): 75

Note: Discharge (34.6 Amps), Charge (5.5 Amps) With V/L Vt4 (1.440 V/C)

Cell Design: Old Pellon (Calculated 55 A/H)
CX Prior To Each Shadow Period

Key:	Cell No
_____	Cell 1
_____	Cell 2
_____	Cell 3
_____	Cell 4
_____	Cell 5





START OF SHADOW:

5/17/88

RECERTIFICATION

Pack: 250B Manuf: GE 50 AH

Shadow #12 - Cell Voltage vs Day

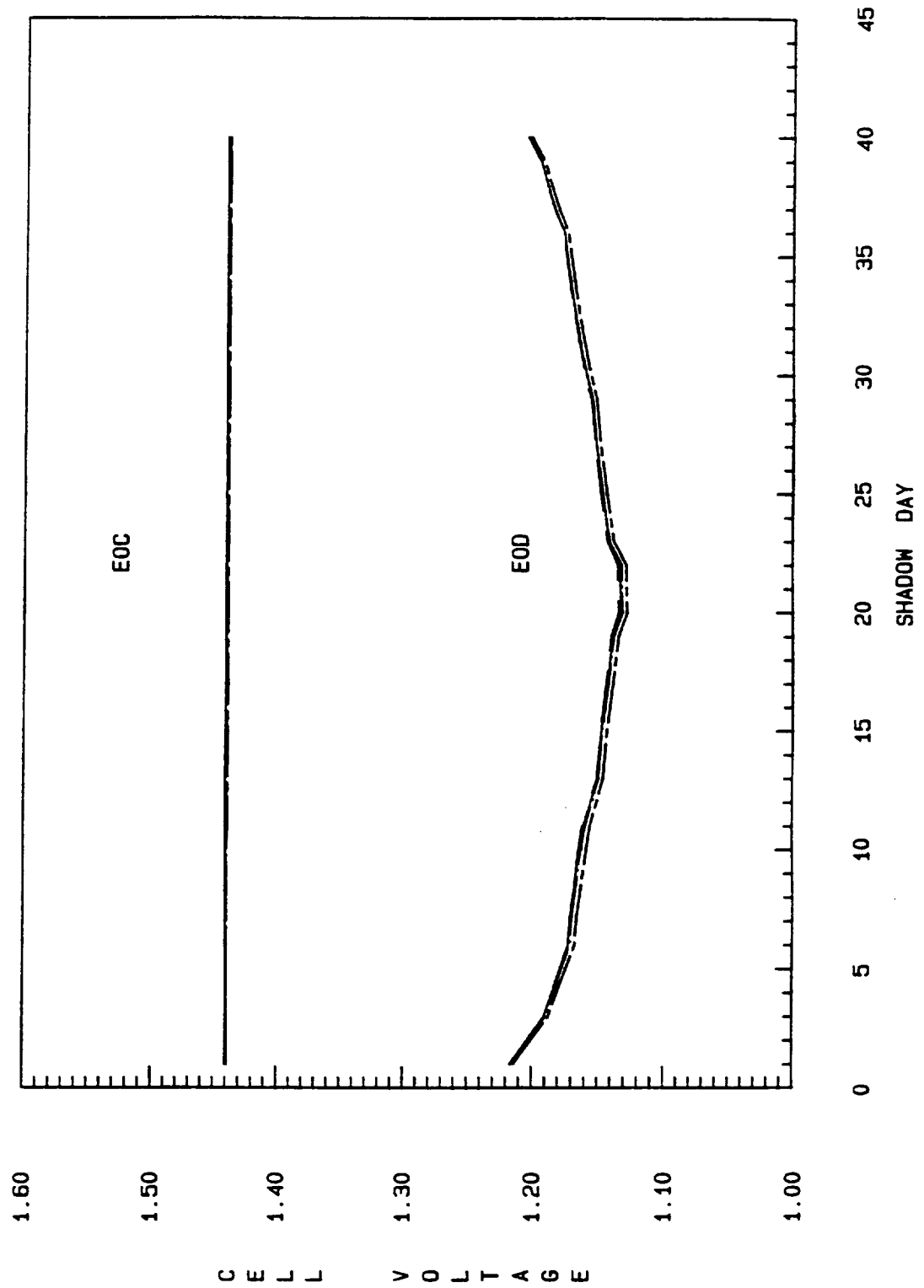
Cycle: 551 to 591 Temp (C): 0 DOD(%): 75

Note: Discharge (34.6 Amps). Charge (5.5 Amps) With V/L Vt 4 (1.440 V/L)

Cell Design: New Pellon (Calculated 55 A/H)

CX Prior To Each Shadow Period

Key: Cell No
____ Cell 1
____ Cell 2
____ Cell 3
____ Cell 4
____ Cell 5





START OF SHADOW

5/17/88

RECERTIFICATION

Pack: 250C Manuf: GE 50 AH

Shadow #12 - Cell Voltage vs Day

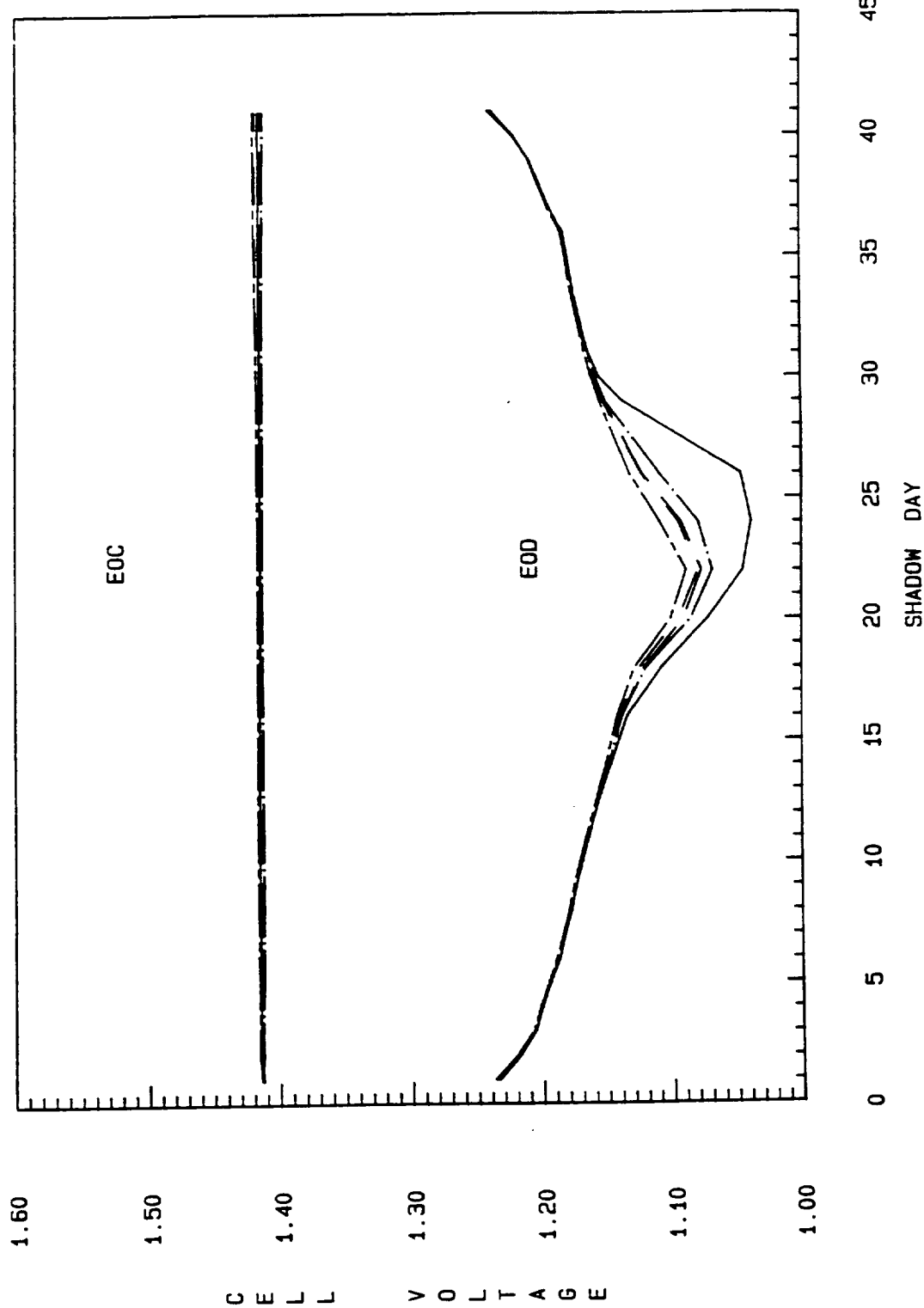
Cycle: 551 to 591 Temp (C): 20 DOD(%): 75

Note: Discharge (32.7 Amps), Charge (5.2 Amps) With V/L Vt 5 (1.414 V/C)

Cell Design: New Pellon (Calculated 52 A/H)

CX Prior To Each Shadow Period

Key: Cell No
Cell 1
Cell 2
Cell 3
Cell 4
Cell 5





START OF SHADOW

5/17/88

RECERTIFICATION

Pack: 250D Manuf: GE 50 AH

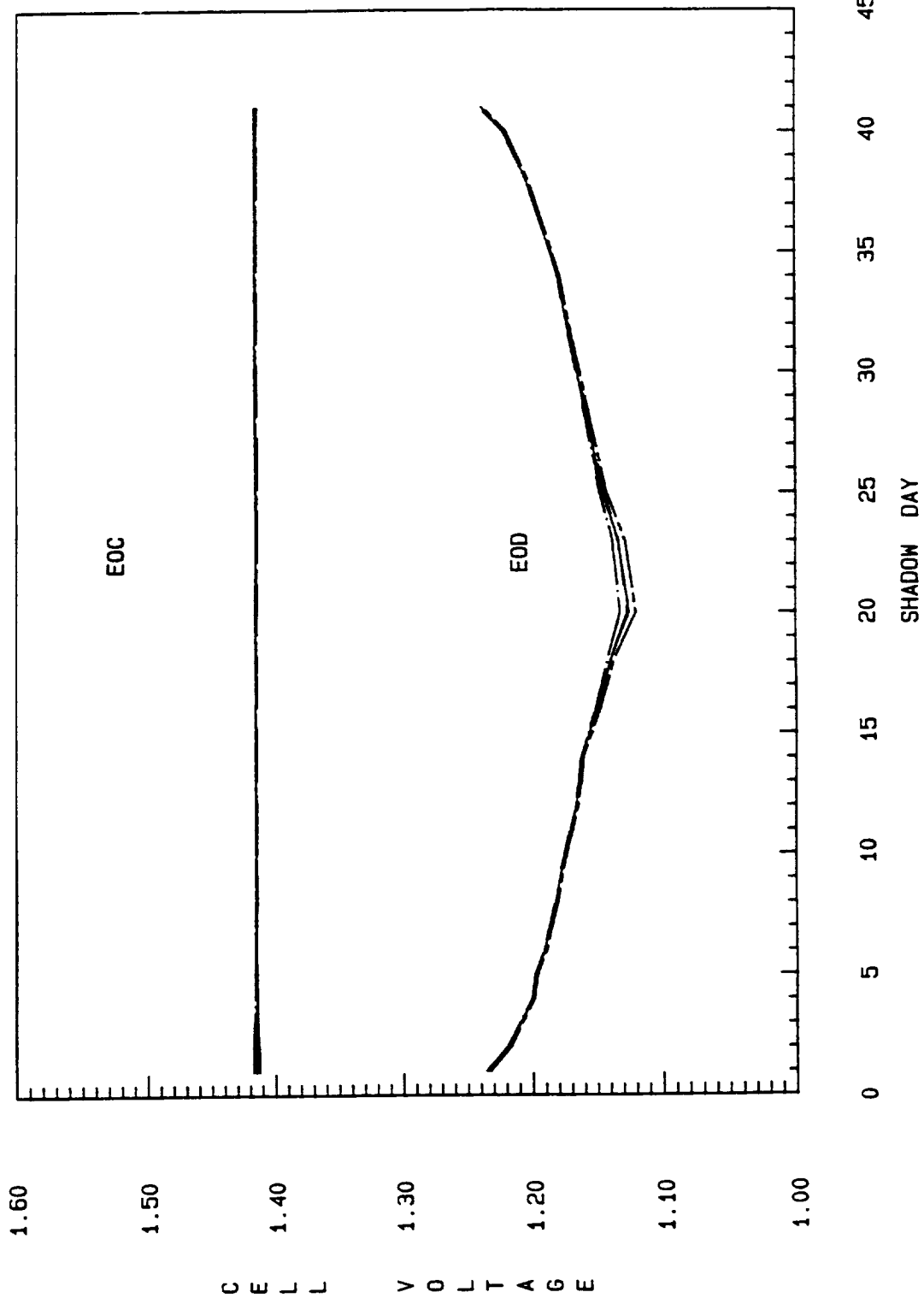
Shadow #12 - Cell Voltage vs Day

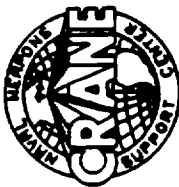
Cycle: 551 to 591 Temp (C): 20 DOD(%): 75

Note: Discharge (32.7 Amps), Charge (5.2 Amps) With V/L Vt 5 (1.414 V/C)

Cell Design: New Pellon (Calculated 52 A/H)
CX Prior To Each Shadow Period

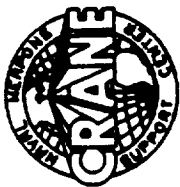
Key: Cell No
____ Cell 6
-- -- Cell 7
-- -- Cell 8
-- -- Cell 9
-- -- Cell 10





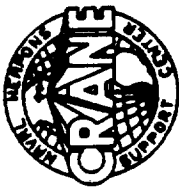
ANALYSIS OF TEST RESULTS

- TEST DATA ANALYZED
 - DATA FROM THIS TEST
 - DATA FROM NASA QUALIFICATION TEST ON GE 50 AH NiCd CELLS WITH PELLON 2536 SEPARATOR AND PASSIVATED POSITIVE PLATES
- VARIABLES THAT HAVE BEEN CONSIDERED
 - CELL TYPE OR DESIGN
 - LIGHTWEIGHT VS STANDARD DESIGN
 - TREATMENT OF NEGATIVE ELECTRODE
 - PASSIVATION OF POSITIVE ELECTRODE
 - ADDITIVES TO POSITIVE ELECTRODE
 - SEPARATION MATERIAL (PELLON 2505 & 2536)
 - AMOUNT OR LEVEL OF CELL COMPONENTS
 - POSITIVE AND NEGATIVE ELECTRODES
 - COATED WEIGHT (SINTERED MATERIAL)
 - IMPREGNATED WEIGHT
 - POROSITY/NICKEL ATTACK (POSITIVE ELECTRODE ONLY)
 - ELECTROCHEMICAL CAPACITY
 - THICKNESS
 - ELECTROLYTE LEVEL



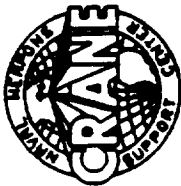
CORRELATIONS OBSERVED

- **BETTER CELL PERFORMANCE OBSERVED WITH FOLLOWING:**
 - **STANDARD RATHER THAN LIGHTWEIGHT DESIGN**
 - **TEFLONATED RATHER THAN SILVERED NEGATIVES**
 - **PELLON 2505 RATHER THAN 2536**
 - **NORMAL RATHER THAN THICKER ELECTRODES**
 - **MORE ELECTROLYTE**
- **ABOVE CORRELATIONS BASED ON SMALL SAMPLING**
- **CORRELATION DOES NOT NECESSARILY IMPLY CAUSE AND EFFECT**
- **NUMBER AND TYPES OF CORRELATIONS IMPLY MORE THAN ONE PROBLEM OR CAUSE**



NEW NiCd CELL QUALIFICATION PROGRAM

- **NEW PROGRAM FOR GENERIC QUALIFICATION OF
AVAILABLE NiCd CELLS**
- **SPONSORED BY AIR FORCE AND NAVY**
- **CONTINUE EVALUATION OF GATES CELL FROM PREVIOUS
TEST PROGRAM**
- **QUALIFICATION OF PRESENT AND NEW DESIGN CELLS**
 - **GATES**
 - PRESENT INTERIM DESIGN**
 - FUTURE BASELINE DESIGN**
 - **SAFT/FRANCE**
 - STANDARD DESIGN**
 - LIGHT-WEIGHT DESIGN**
 - **HUGHES ADVANCED DESIGN**



CONCLUSIONS

- DO NOT HAVE GENERIC QUALIFICATION OF CELLS USING

PELLON 2536

- DATA TO DATE DOES NOT SUPPORT QUALIFICATION
- POOR ELECTROLYTE DISTRIBUTION AND LOCALIZED SEPARATOR HEATING APPEAR TO BE ASSOCIATED WITH POOR PERFORMANCE OF CELLS WITH 2536 MATERIAL
 - CAUSE OF PROBLEM HAS NOT BEEN VERIFIED
 - MORE THAN ONE PROBLEM IS PROBABLY RESPONSIBLE FOR THE OBSERVED CELL PERFORMANCE
- WILL CONTINUE TO EVALUATE THESE GATES CELLS
 - CONTINUE CYCLING OF GEO PACKS AND LEO PACKS WITH LIMITED FAILURES
 - PERFORM ADDITIONAL DPA'S
- WILL INITIATE COMPREHENSIVE TEST PROGRAM TO CHARACTERIZE AND EVALUATE NiCd CELLS THAT ARE/WILL-SOON-BE AVAILABLE
 - CELLS FROM DIFFERENT MANUFACTURERS
 - ADVANCED AS WELL AS STANDARD DESIGNS

SESSION III

NICKEL-HYDROGEN TECHNOLOGY

SESSION I - Current Programs

Chairman: P. Ritterman

NICKEL HYDROGEN LOW EARTH ORBIT TESTING

- A Coordination of Efforts -

Presented at The NASA/GSFC Battery Workshop

November 1-3, 1988

Kenneth H. Fuhr
Martin Marietta Astronautics
Denver, Colorado

Thomas B. Miller & Theresa Romanofsky
NASA Lewis Research Center
Cleveland, Ohio

Samuel W. Donley & Carol A. Hill
The Aerospace Corporation
El Segundo, California

Penni Dalton & Steve Hall
Naval Weapons Support Center
Crane, Indiana

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November 1-3, 1988

PAGE 238

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Air Force

Nickel-Hydrogen Test Program

Objective

- To demonstrate Nickel-Hydrogen performance in LEO applications and determine whether use in MAO will enable the achievement of performance levels superior to current Nickel-Cadmium capabilities.
- To demonstrate Nickel-Hydrogen cell performance in pulse applications.
- To demonstrate that the Manufacturing Technology Program (MANTECH) cells are capable of performing in high orbit as well as LEO.

Air Force Test Description

Approach

- Test cells from Gates Energy Products, Eagle-Picher Industries, Whittaker-Yardney, and Hughes Aircraft.
- Test enough cells from each manufacturer to provide a comparison and to establish a statistically significant data base at an adequate confidence level.
- Demonstrate the capability of achieving a minimum of 30,000 LEO cycles at 40% DOD, 20,000 LEO cycles at 60% DOD, and 5,000 cycles at 80% DOD in MAO or high orbit.
- LEO cells to be tested at -5°C and $+10^{\circ}\text{C}$; MAO cells to be tested at $+10^{\circ}\text{C}$.
- Test a small number of cells at 25% DOD to provide correlation with present Nickel-Cadmium testing and life data base.

Aerospace Corporation

Los Angeles, California

Objective

- Verify life capability of Nickel-Hydrogen cells in LEO orbit regime containing high rate (5C) pulses.

Approach

- Life test ten 3.5 inch and five 4.5 inch diameter cells.
- Acceptance and characterization testing to be done at NWSC and life testing to be performed at Aerospace.
- Life test to be at 10° C and an average of 60% DOD.

Martin Marietta Astronautics

Denver, Colorado

Objective

- To develop a data base for LEO use of Nickel-Hydrogen cells and batteries.

Approach

- Life cycle in a simulated 90 minute low earth orbit consisting of a 35 minute discharge period and a 55 minute charge period.
- Procure cells from domestic manufacturers of 50 and 100 ampere-hour capacities.
- Test cells of all designs including advanced designs.
- Cells tested at 10° C and 20° C, 40 % and 60% depths of discharge.
- Oldest cells on test have accumulated over 13,500 cycles at 40% DOD.

NASA Marshall Space Flight Center

Huntsville, Alabama

Objective

- LEO life cycle test Nickel-Hydrogen cells to meet needs of the Hubble Space Telescope.

Approach

- Life cycle test 14 COMSAT design 30 ampere-hour cells.
- Life cycle test 12 Air Force design 33 ampere-hour cells.
- Place 12 Air Force design, HST specific, cells on test mid November, 1988.
- Place six - 23 cell HST flight configuration batteries on test January - February, 1989.

NASA Marshall Space Flight Center

Huntsville, Alabama

Test Parameters

- 90 minute simulated orbit, 35 minute discharge period, 55 minute charge period, 10° C, 10 - 12 % DOD.

- Oldest cells on test have accumulated over 11,000 cycles.

NASA Lewis Research Center

Cleveland, Ohio

Objective

- Life test Nickel-Hydrogen cells specific to Space Station requirements.

Approach

- Testing to be a shared responsibility between LERC and Rocketdyne/Ford.
- Cells to be 65 and 81 ampere-hour capacities from three vendors...
 - 150 cells to be 65 ampere-hour standard Air Force design.
 - 60 cells to be 65 ampere-hour advanced design.
 - 105 cells to be 81 ampere-hour advanced design.
- Above cells to be tested at -5° C and +10° C, 35% and 60% DOD at the NWSC, Crane, Indiana
- Life test 40 cells at LERC at -5° C and +10° C, 35% DOD.

Hughes / NASA Lewis

Objective

- Investigate Air Force design cells with NASA Lewis advanced modifications.

Approach

- Life cycle cells at 80% DOD and 10° C to ambient.
- Supply NASA Lewis (John Smithrick) with cells for in house testing.

GE Astro Space Division

Princeton, New Jersey

Objective

Evaluate Nickel-Hydrogen for Low Earth Orbit applications.

Approach

- Life test 1981 version of Hughes 50 ampere-hour cells and 70 ampere-hour MANTECH design cells.
 - Hughes cells being tested at 10° C, 40% and 60% DOD.
 - MANTECH cells being tested at 10° C, 30% and 50% DOD.
-
- GE has launched 30, 35, 40, and 50 ampere-hour COMSAT design cells for GEO applications, and has demonstrated 30 GEO seasons without failure with up to 70% DOD on ground test.



Redondo Beach, California

Objective

- To obtain parametric and life test data for Nickel-Hydrogen specific to the AXAF program.

Approach

- Test 80 ampere-hour cells at 0 - 10° C and 20 - 30 % DOD.
- 30 - 50 cells on order from several manufacturers.
- Testing to start in March, 1989.

Pawcatuck, Connecticut

Objective

Life test MANTECH phase II and phase III cells.

Approach

- Two MANTECH phase II cells tested at 80% DOD and 20° C for 5000 cycles, then reduced to 60% DOD for an additional 3800 cycles, then further reduced to 35% DOD and 20° C for 4200 cycles.
 - One phase III cell tested at 35% DOD and 20° C for 4200 cycles.
-
- During initial 2000 cycles on the phase II cells, a variety of recharge fractions was experimented with and certain test anomalies were encountered.

Eagle-Picher Industries, Inc.

Joplin, Missouri

Ojective

- Life cycle test Eagle-Picher cells of the COMSAT design, Air Force design, and combinations of the two.

Approach

- All testing is at 5 +/- 3° C.
- The charge and discharge rates are based on nameplate capacity and testing is either LEO or an accelerated cycle.
- Cells being tested at 15, 30, 35, and 50% DOD.

NIH2 LEO LIFE TEST AT NWSC/CRANE: UPDATE & STATUS

(NOT SUBMITTED)

S. DONLEY, C. HILL, A. MENICHELLO, AEROSPACE CORP

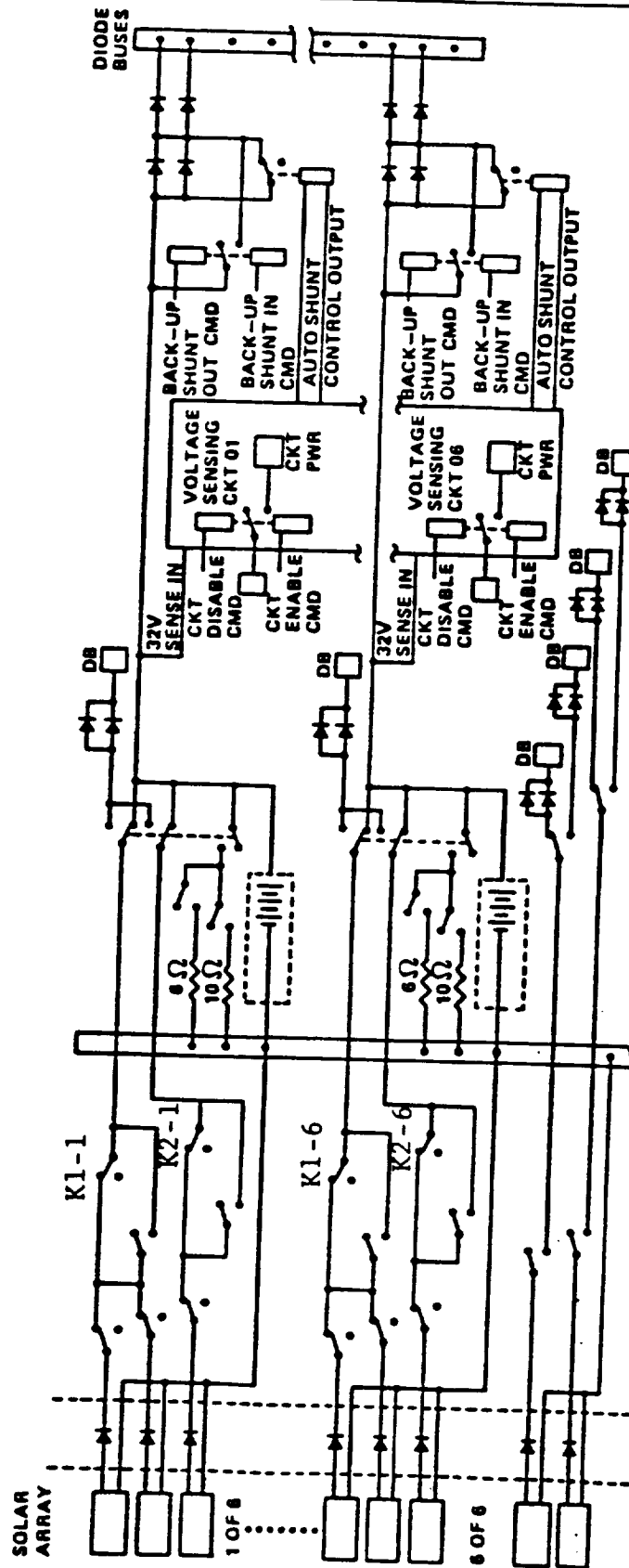
P. DALTON, R. HAAG, S. HALL, NWSC

HST NIH2 BATTERY OPERATION IN LEO

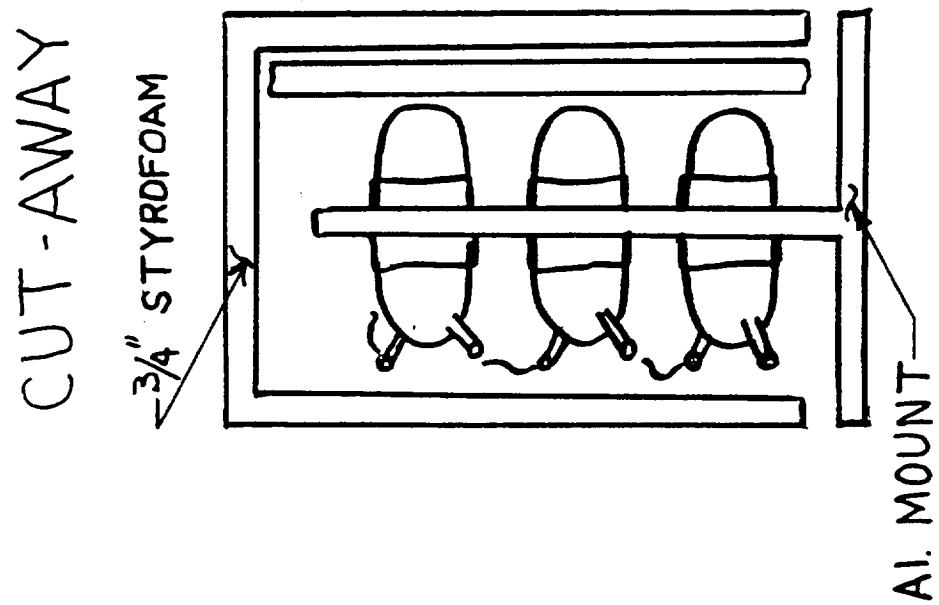
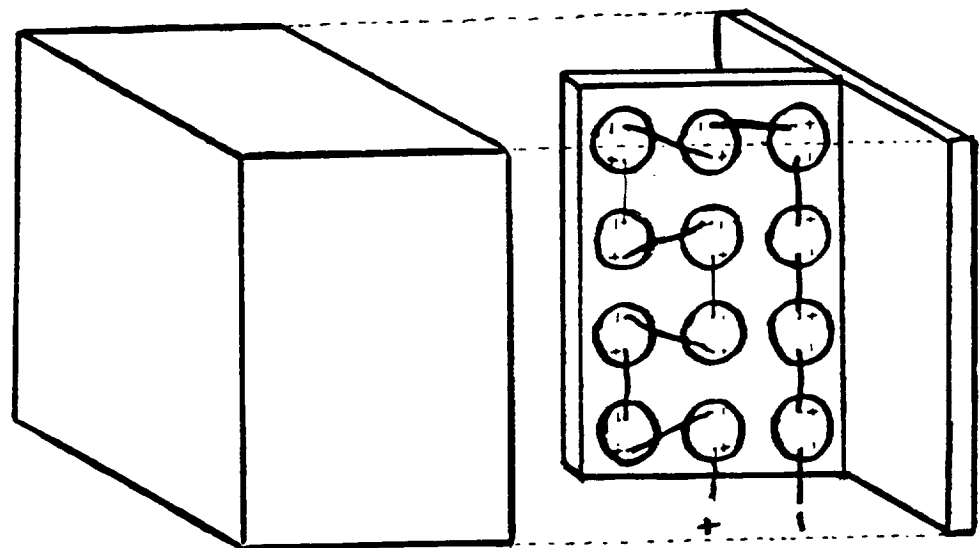
ROY LANIER, NASA/MSFC

ORGANIZATION: EB12		MARSHALL SPACE FLIGHT CENTER		NAME: ROY LANIER
CHART NO.:		SPACE TELESCOPE		DATE:

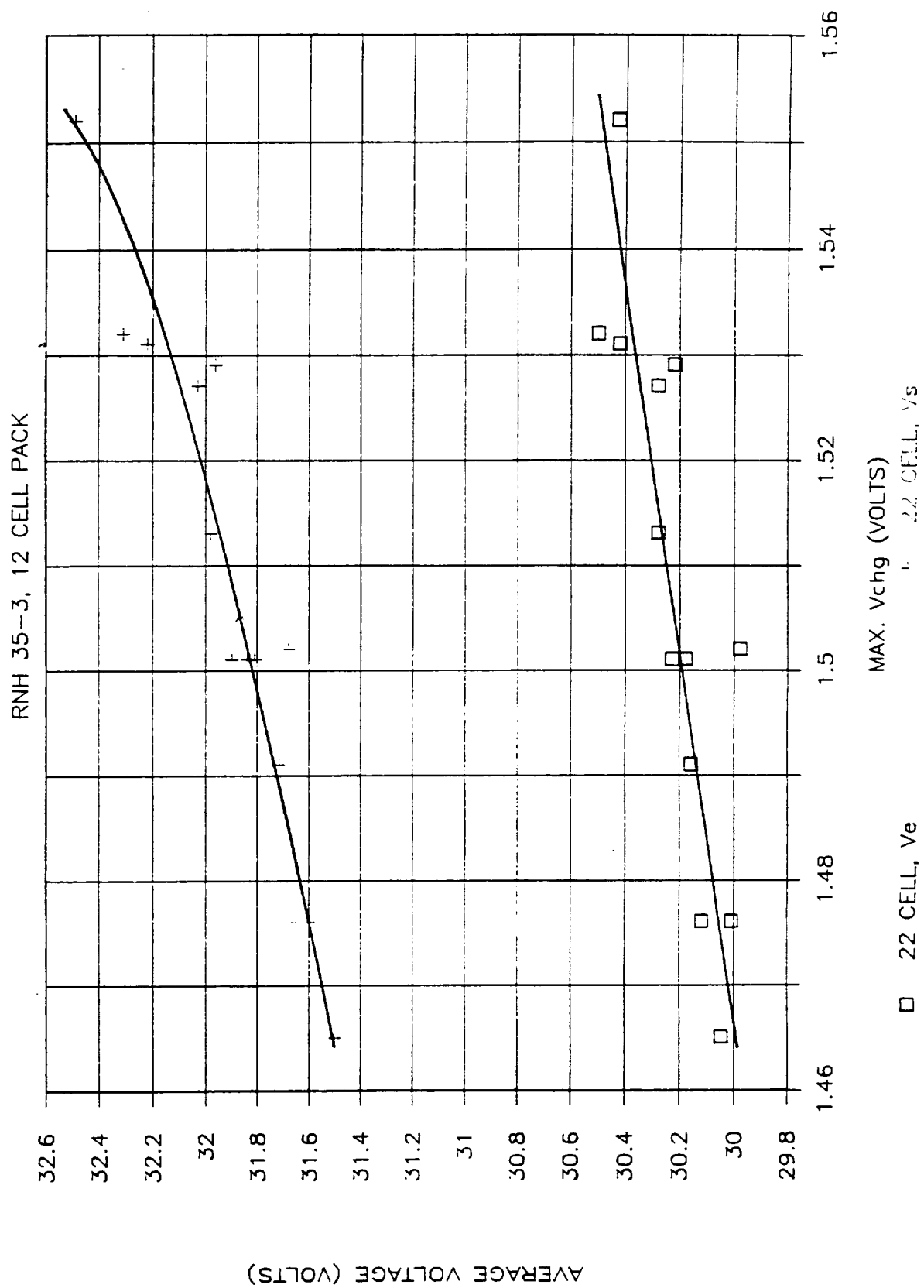
ELECTRICAL POWER SYSTEM



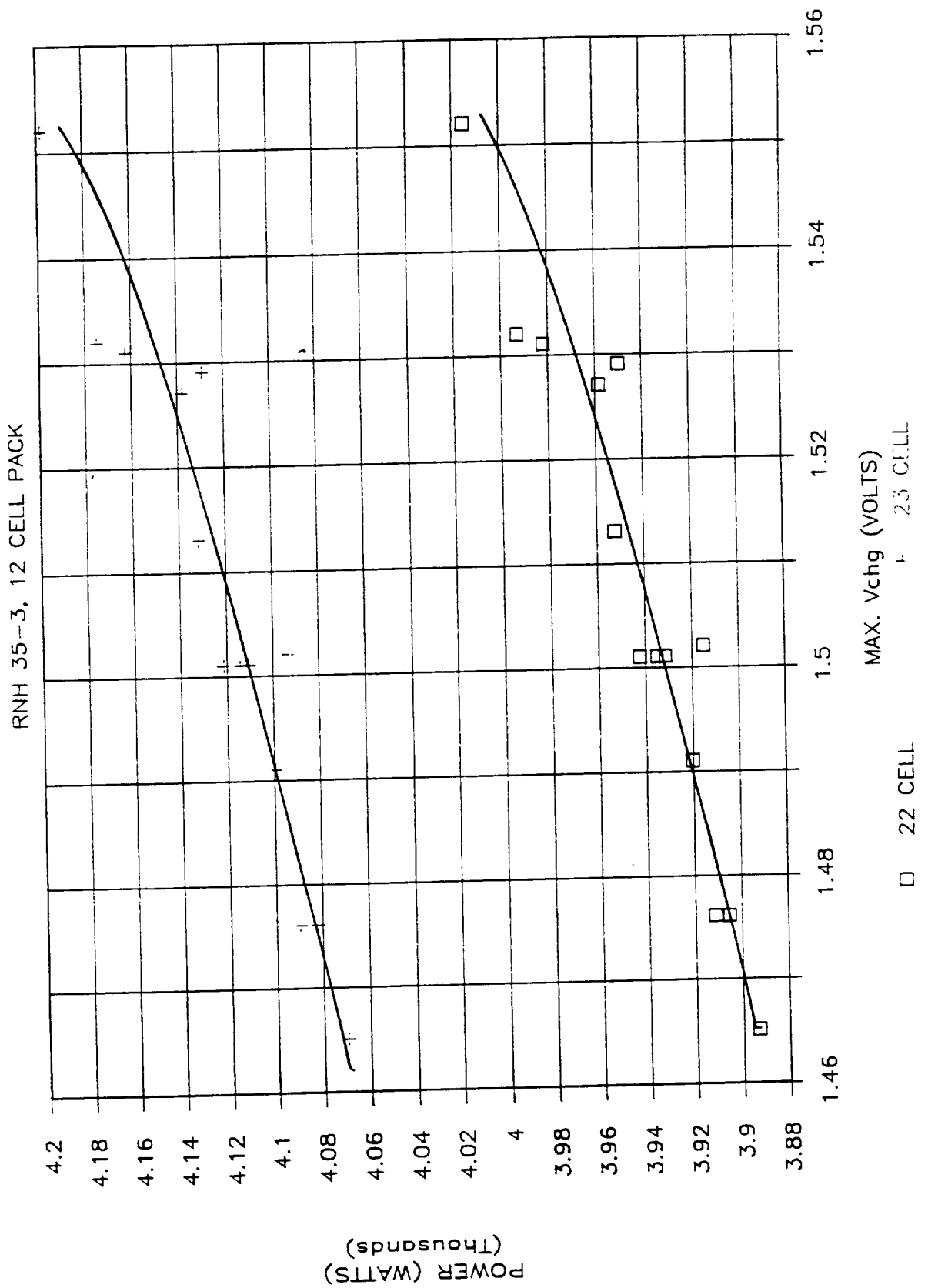
Ni-H₂ 12 CELL PACK



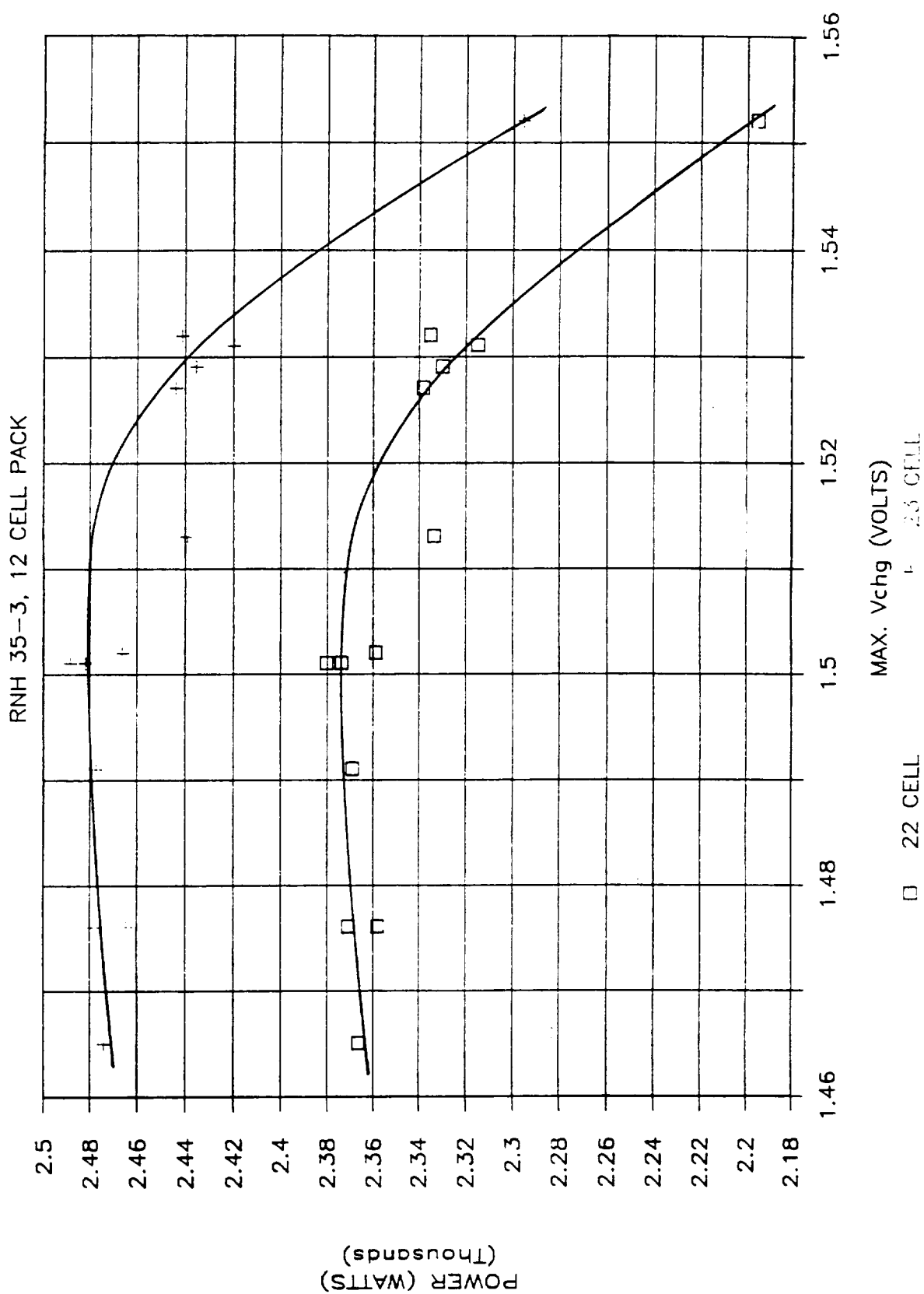
Ni-H₂ AVERAGE VOLTAGES VS. CHG. VOLTS



Ni-H2 SOLAR ARRAY POWER VS. CHG. VOLTS

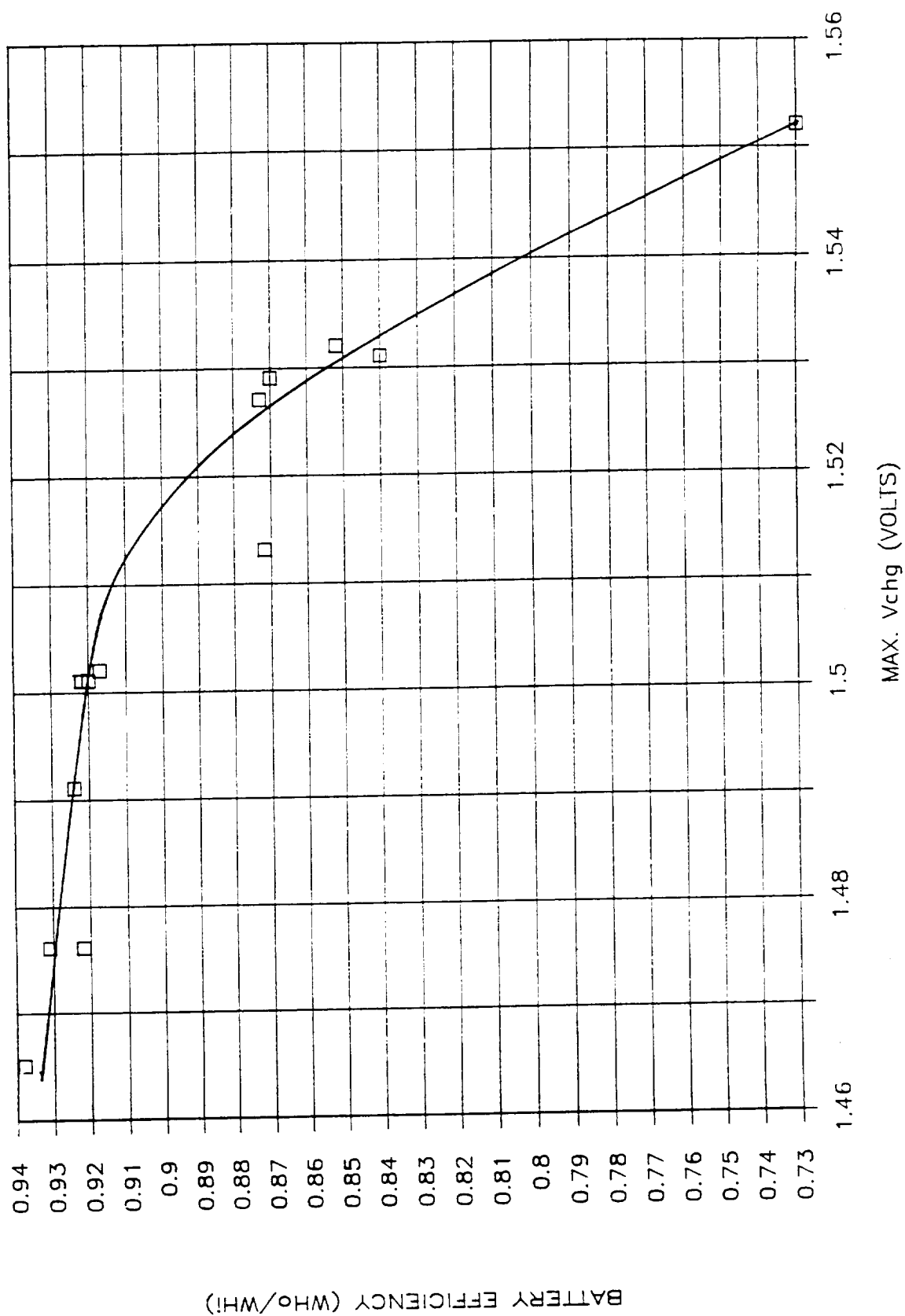


Ni-H₂ POWER AVAILABLE VS. CHG. VOLTS



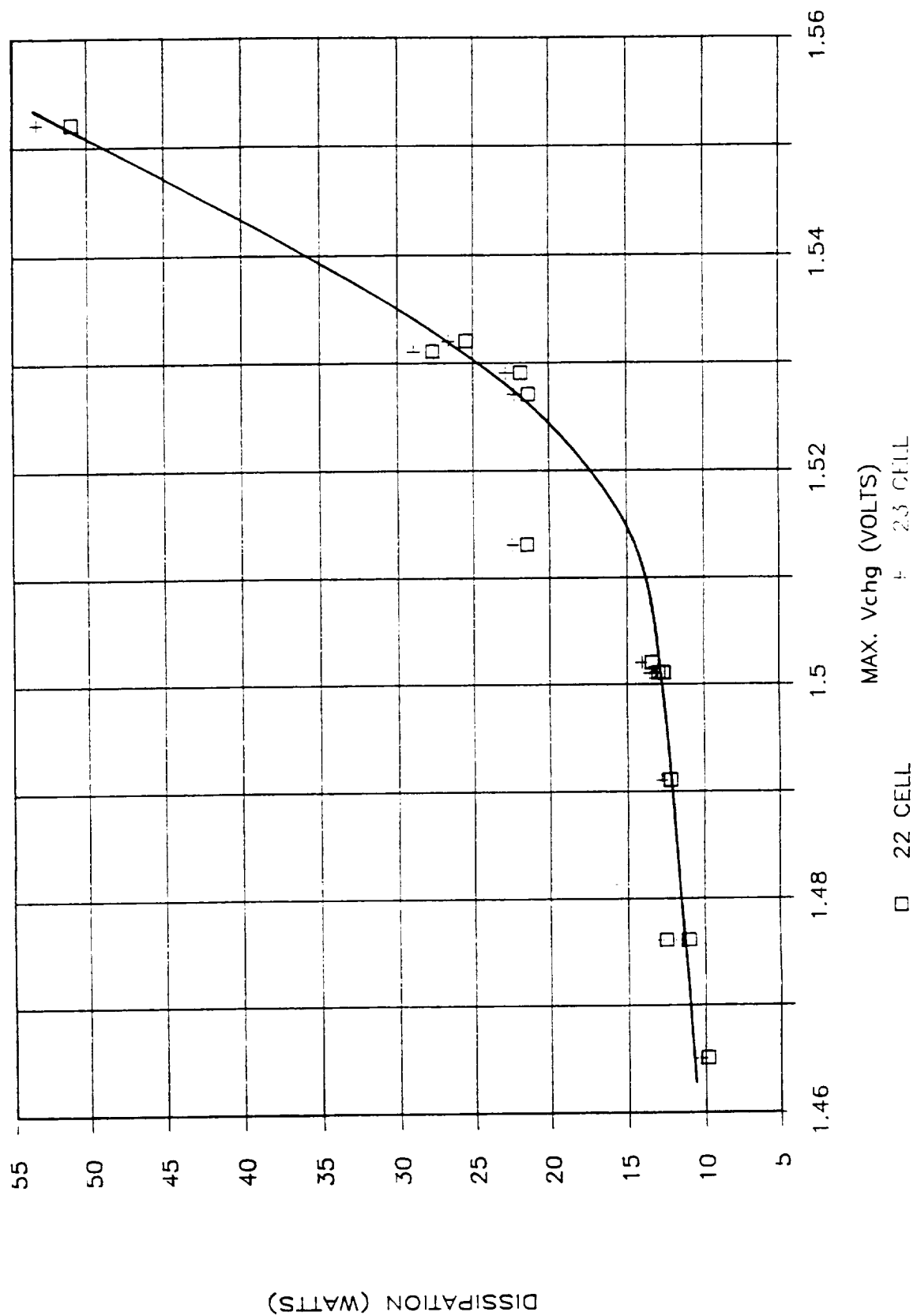
Ni-H2 BATTERY EFFICIENCY VS. CHG. VOLTS

RNH 35-3, 12 CELL PACK



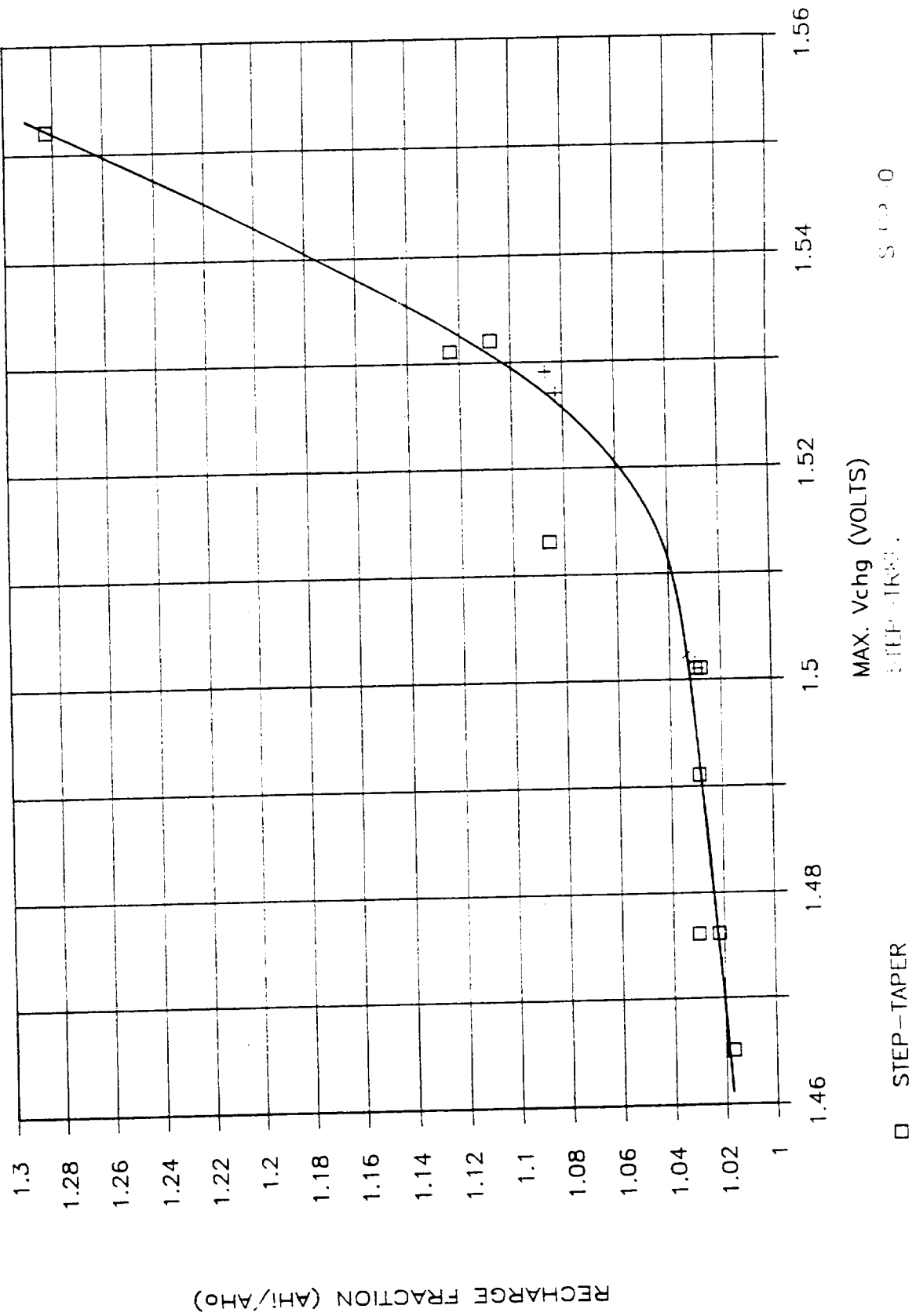
Ni-H2 BAT. DISSIPATION VS. CHG. VOLTS

RNH 35-3, 12 CELL PACK



Ni-H₂ RECHARGE FRACTION VS. CHG. VOLTS

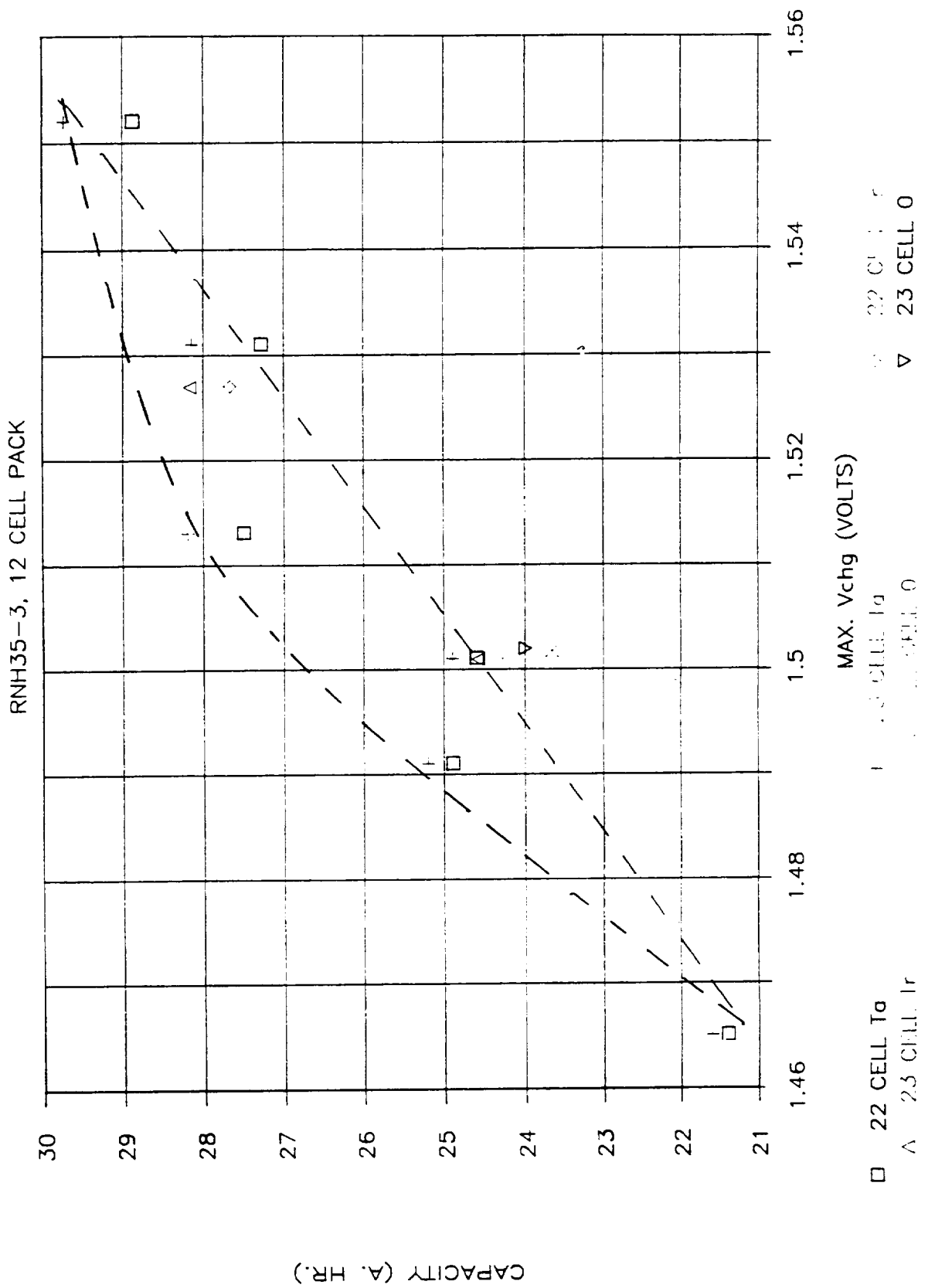
RNH 35-3, 12 CELL PACK



STEP-1633

□ STEP-TAPER

Ni-H₂ CAPACITY VS. CHG. VOLTS



Ni-H₂ Battery Cell Life Test Update

Lee Miller and Brad Burris
Eagle-Picher Industries, Inc.

Abstract

Eagle-Picher Industries has been conducting LEO type life cycle testing on Ni-H₂ battery cells for approximately six (6) years. Over 100 cells have been introduced into the cyclic regimes and some groups are now approaching 40,000 cycles. The depth-of-discharge (DOD) selected for evaluation has ranged from 15% to 50%.

This paper offers a test result summary update for the longer-term cell groups.

Introduction

Eagle-Picher Ni-H₂ battery cells have been successfully tested by both domestic and foreign spacecraft manufacturers and users in simulated GEO life cycle regimes. With this already established and growing mission type data base, Eagle-Picher elected to direct its resources toward LEO life cycle type testing.

To minimize equipment and operational, complexity and cost, the test regimes feature constant temperature (50 - 100°C), constant current charge and discharge and constant, manually selected C/D ratios. Both real-time 90 minute cycle and accelerated 45 minute cycle regimes are utilized. Cell performances at DOD's of 15% 30% and 50% are being evaluated. (See Exhibit #1)

As of this date, the longest-term cell groups are now approaching 40,000 cycles with good performance characteristics. Additional details concerning this test activity were presented at the 23rd (1988) IECEC (1).

Discussion

Over the approximate six (6) year test period, various cells groups have been added to the test regimes and the total count now exceeds 100 cells.

In addition to numbers, various technologies were introduced for evaluation. These include 1) cell capacity size (30, 50 and 80 AH), 2) positive electrode mechanical strength variations, 3) separator types (asbestos and Zircar), 4) electrolyte quantities, 5) electrode stack geometries (pineapple and truncated electrodes), and 6) electrolyte additives (LiOH). (See Exhibit #2)

Results

Exhibits #3 - #5 present a data graph, end-of-charge/discharge voltages and measured capacity respectively for a group of 50 AH rated cells. These cells are tested in an accelerated, 45 minute, LEO cycle regime at a 15% DOD. Stable performance, good end-of-discharge voltages and no measurable capacity loss results continue to be recorded over 38,000 cycles.

Exhibits #6 - #8 present the same data for a group of 30 AH rated cells in a real-time, 90 minute cycle regime at a 30% DOD. These cells were accidentally subjected to a dead-short condition resulting in high heat generation (as a result, cells 003, 004 and 012 were lost due to terminal seal leakage). The remaining cells have now accumulated 5,000 more cycles for a total in excess of 26,000 cycles while maintaining the same good performance results as noted for the above group.

Exhibits #9 and #10 present data graphs for 80 AH rated cells in a real-time, 90 minute cycle regime at a 50% DOD. At this level of DOD, cell performance was demonstrated to be more sensitive to design technologies. As indicated in Exhibit #9, the combination of low positive electrode mechanical strength

and low electrolyte quantity did not perform well. However, when the combination included high electrolyte quantities (Exhibit #10), these cells have continued to perform well through 10,000 cycles.

Conclusion

A six (6) year life cycle test effort has demonstrated the Ni-H₂ battery system's capability to support long-term LEO type missions up to and including 30% DOD's. The data further suggest DOD's in excess of 30% may be equally viable; however, careful assessment and proper selection of design technologies will be important.

In support of this latter objective, Eagle-Picher plans to continue expansion of its LEO life cycle test effort. A few new technologies which are now being incorporated or considered are listed in Exhibit #11.

References

- (1) D.K. Coates and R.M. Barnett, "Nickel-Hydrogen Cell Life Testing", Proceedings of the 23rd Intersociety Energy Conversion Engineering Conference (IECEC), August 1988.

EXHIBIT #1
Typical LEO Test Regime Features

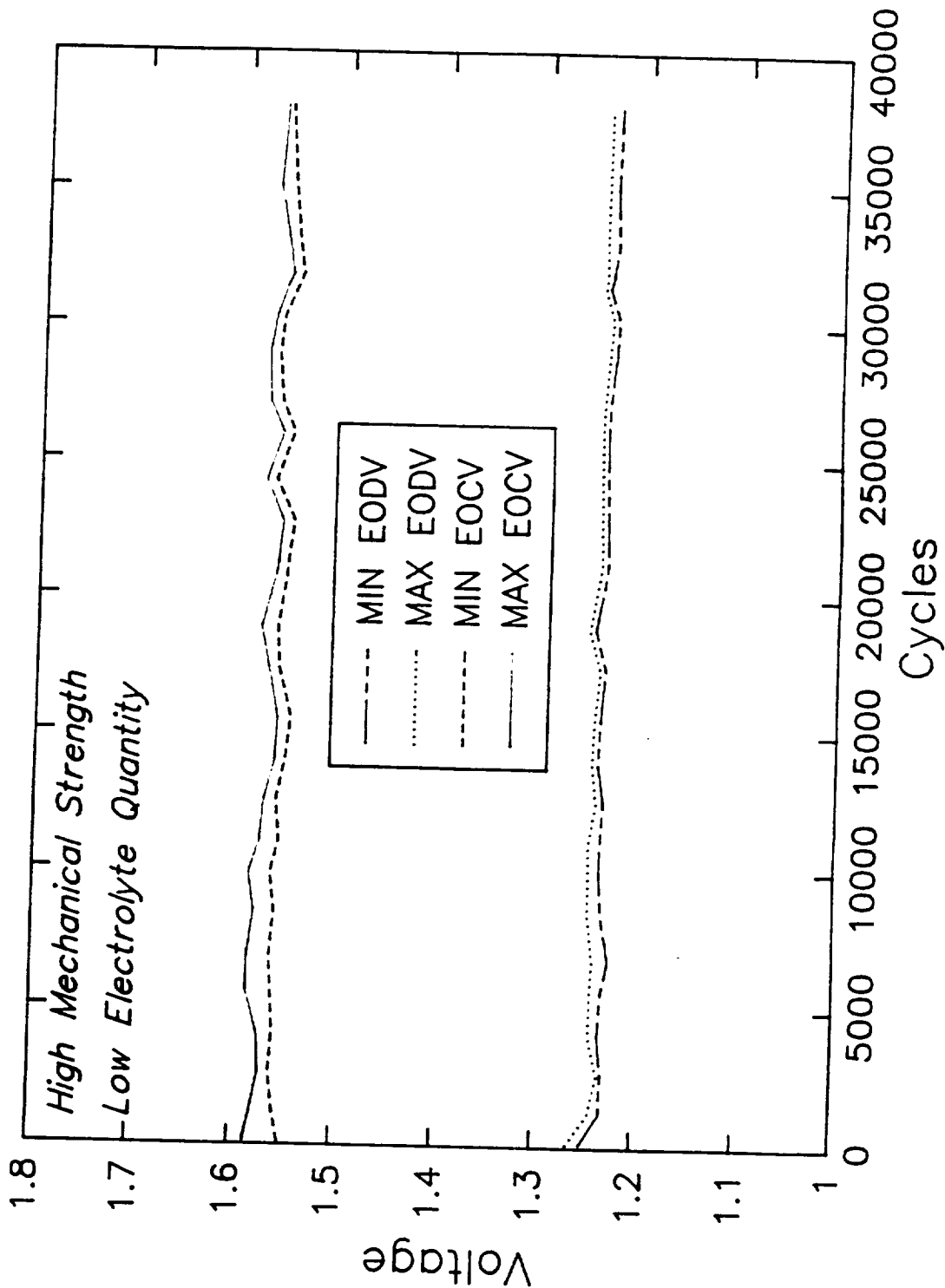
- Constant temperature ($5^{\circ} - 10^{\circ}\text{C}$)
- Constant current charge and discharge
- Constant, manually selected charge/discharge ratios
- Real-time 90 minute and Accelerated 45 minute cycle regimes
- Depths-of-Discharge (DOD) 15%, 30%, and 50%

EXHIBIT #2

Various NiH₂ Battery Cell Technologies
Evaluated In LEO Life Cycle Testing

- Cell capacity size
- Positive electrode mechanical strength
- Separator type
- Electrolyte quantity
- Electrode stack geometry
- Electrolyte additive

50-AH Battery Cells 15% DOD



ACCELERATED LIFE TEST

DATE: 10/24/87

RNH-50-15

CYCLE: 38060

CHARGE					DISCHARGE			
SN	5 MIN	10 MIN	15 MIN	EOC	5 MIN	10 MIN	15 MIN	EOC
01	1.4099	1.4517	1.4819	1.5480	1.3676	1.3207	1.2869	1.2482
02	1.4157	1.4578	1.4868	1.5514	1.3628	1.3170	1.2834	1.2448
03	1.4195	1.4618	1.4895	1.5555	1.3591	1.3124	1.2798	1.2412
04	1.4167	1.4590	1.4879	1.5536	1.3618	1.3151	1.2815	1.2431
05	1.4165	1.4586	1.4864	1.5524	1.3618	1.3152	1.2830	1.2447
06	1.4082	1.4504	1.4804	1.5464	1.3701	1.3232	1.2890	1.2505
07	1.4195	1.4621	1.4901	1.5556	1.3573	1.3106	1.2778	1.2392
08	1.4175	1.4601	1.4878	1.5541	1.3608	1.3141	1.2814	1.2425
09	1.4171	1.4593	1.4884	1.5554	1.3618	1.3148	1.2809	1.2421
10	1.4187	1.4607	1.4899	1.5572	1.3610	1.3140	1.2804	1.2420
11	1.4324	1.4758	1.5045	1.5755	1.3446	1.2965	1.2625	1.2210
12	1.4137	1.4564	1.4847	1.5533	1.3662	1.3182	1.2846	1.2454
13	1.4141	1.4562	1.4846	1.5525	1.3653	1.3179	1.2848	1.2463
14	1.4158	1.4575	1.4866	1.5549	1.3660	1.3187	1.2846	1.2458
15	1.4169	1.4580	1.4879	1.5552	1.3671	1.3203	1.2858	1.2474
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	1.4169	1.4585	1.4883	1.5572	1.3667	1.3193	1.2848	1.2459
18	1.4197	1.4611	1.4909	1.5603	1.3646	1.3172	1.2829	1.2440
19	1.4163	1.4580	1.4889	1.5578	1.3693	1.3221	1.2865	1.2470
20	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
21	1.4060	1.4477	1.4802	1.5487	1.3763	1.3286	1.2920	1.2523
22	1.4159	1.4570	1.4897	1.5601	1.3747	1.3273	1.2909	1.2508
23	0.0004	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
24	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
25	1.4392	1.4802	1.5212	1.6095	1.4005	1.3555	1.3158	1.2751
26	1.4313	1.4664	1.4988	1.5533	1.3616	1.3227	1.2924	1.2585
----- STRAIN GUAGES -----								
27	0.010	0.019	0.021	0.022	0.010	0.008	0.005	0.004
28	0.000	0.002	0.002	0.003	0.000	0.000	-0.001	0.000
29	-0.001	0.000	0.001	0.001	-0.001	-0.001	-0.001	-0.001
30	-	.	.	.	.	.	.	.
31	0.000	0.002	0.003	0.004	0.001	0.000	0.000	-0.002
----- CURRENT -----								
00	+19.88	+19.88	+19.88	+19.88	-20.89	-20.90	-20.90	-20.90
----- TEMPERATURE -----								
32	+4.64	+4.66	+4.53	+4.26	+4.07	+4.07	+4.18	+4.37
33	+2.78	+2.73	+2.65	+2.51	+2.32	+2.35	+2.41	+2.62
34	+4.29	+4.13	+3.96	+3.70	+3.53	+3.67	+3.83	+4.07
35	+3.32	+3.24	+3.10	+2.94	+2.81	+2.84	+2.92	+3.05

Exhibit #5

RNH-50-15 LIFE TEST

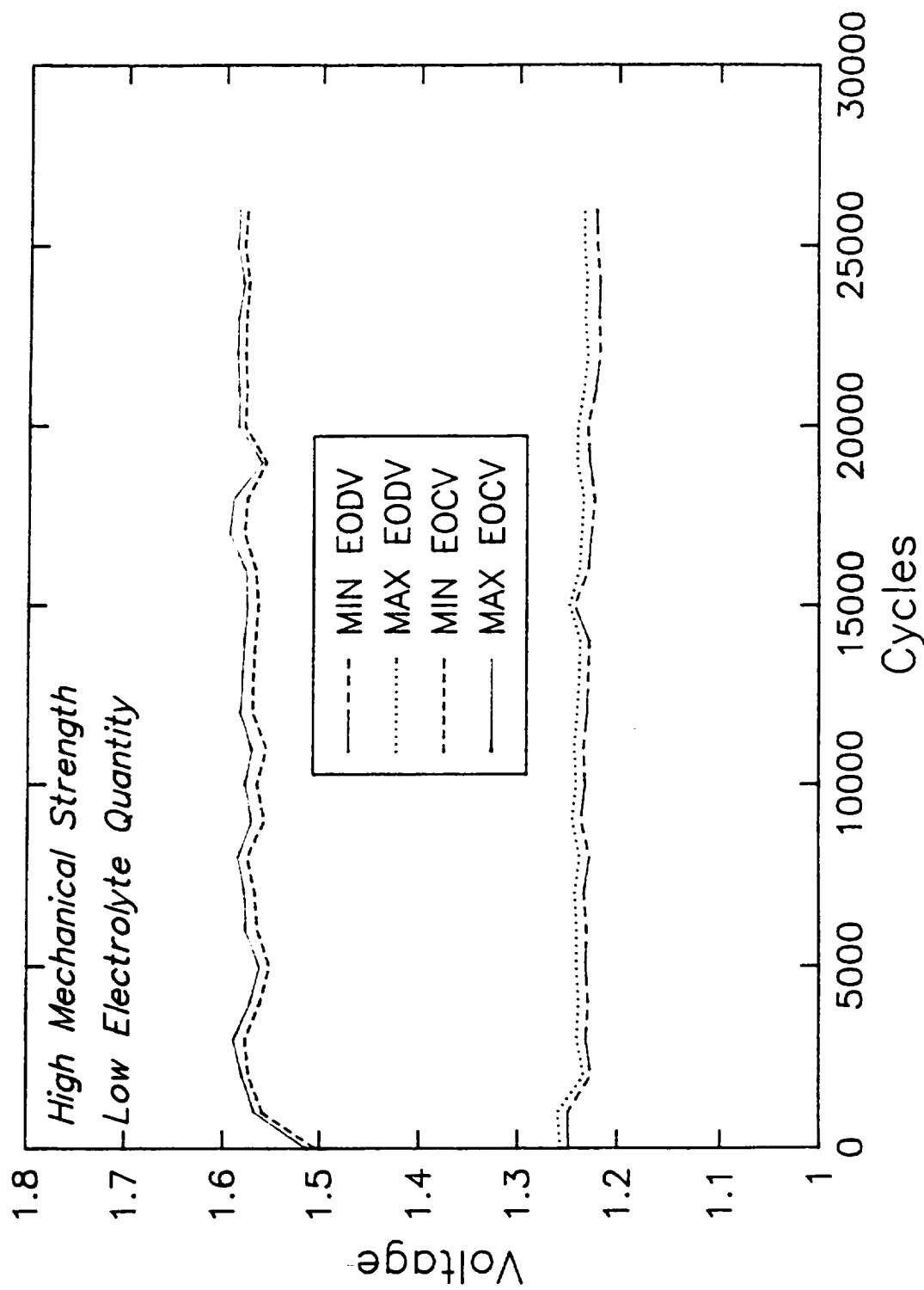
CYCLE CAPACITY DATA SUMMARY

BATT TEMP: 5+-3 DEG C

DISCHG RATE: 25+-0.1 AMP

S/N	#37755
---	-----
001	67.7
002	68.0
003	67.0
004	67.7
005	67.0
006	67.3
007	67.0
008	67.0
009	67.3
010	67.0
011	67.3
012	65.5
013	67.0
014	67.3
015	67.7
016	67.0
017	66.2
018	66.2
019	67.0
020	67.0
021	67.3
022	65.5
023	0.0
024	0.0
025	0.0
026	0.0
AVG	67.0
Std	0.63

30-AH Battery Cells 30% DOD



CYCLE 26200

END-OF-DISCHARGE

```

* 012 -0.0005 U
* 011 +1.2271 U
* 010 +1.2302 U
* 009 +1.2313 U
* 008 +1.2295 U
* 007 +1.2256 U
* 006 +1.2307 U
* 005 +1.2283 U
* 004 -0.0007 U
* 003 -0.0007 U
* 002 +1.2196 U
* 001 +1.2306 U
* CHAN AL DATA PAR AR MSG
* DAY 027 TIME 23:38

```

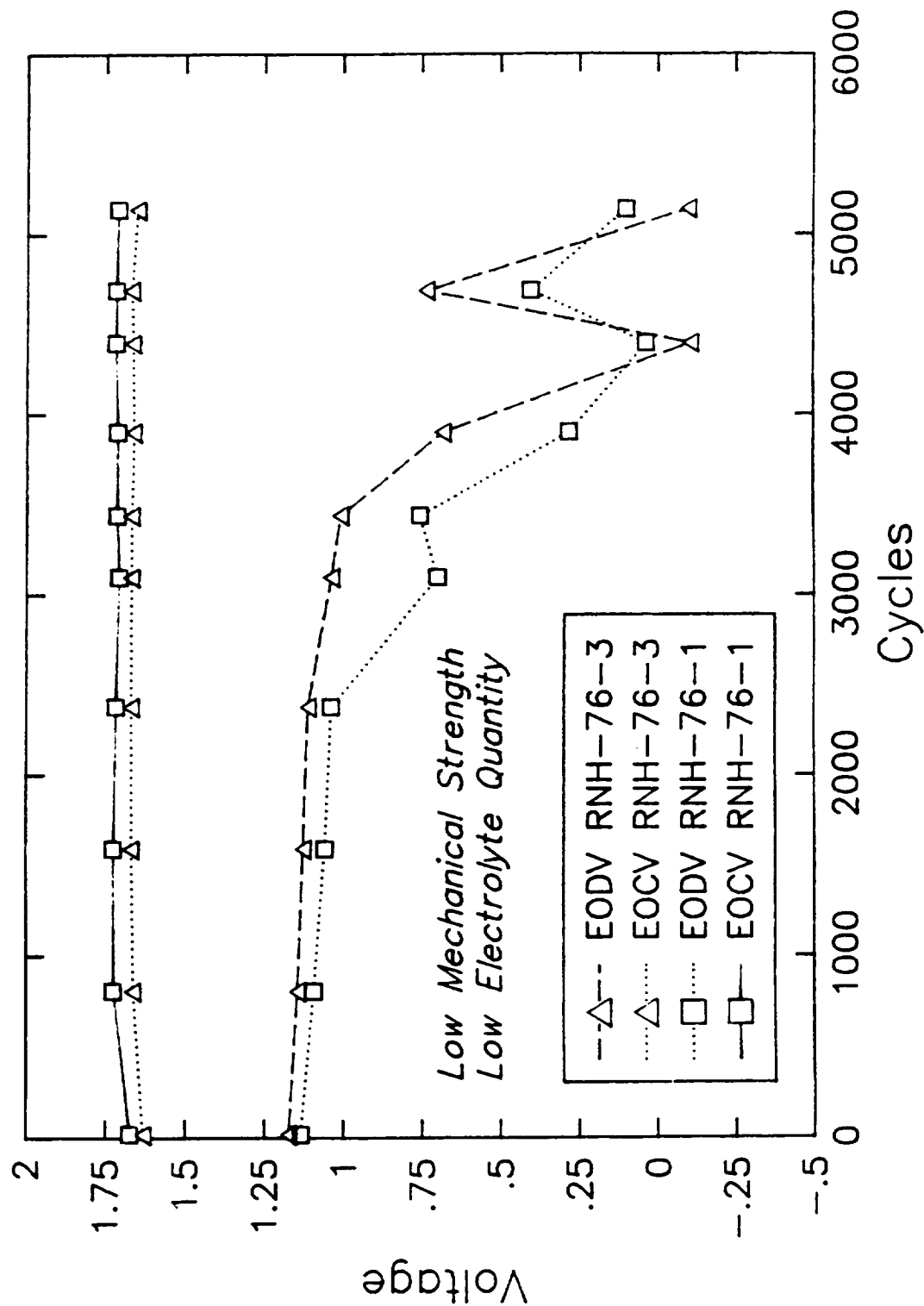
RNH-30-1 LIFE TEST
DISCHARGE CAPACITY SUMMARY

S/N	INIT	#2300	#4200	#4201	#8601	#8603	#10763
---	----	----	----	----	----	----	-----
001	36.0	36.0	37.0	40.0	39.0	39.8	37.5
002	35.4	30.8	32.3	35.1	35.5	36.3	34.8
003	36.0	36.0	37.5	40.0	39.0	39.8	37.5
004	35.6	35.4	36.7	39.8	38.8	39.5	37.2
005	35.0	32.3	33.6	38.0	37.5	38.8	35.8
006	35.8	32.1	34.1	38.0	36.8	38.8	36.2
007	35.3	32.6	34.1	38.2	37.8	39.3	36.2
008	36.0	32.3	34.4	38.2	37.5	39.0	36.8
009	35.8	32.6	34.4	38.2	37.5	39.3	36.8
010	35.8	32.9	35.4	38.5	37.5	39.5	37.0
011	35.3	32.3	33.9	38.2	37.8	39.0	36.2
012	35.3	32.3	33.9	38.2	37.8	39.3	36.2
AVG	35.6	33.1	34.8	38.4	37.7	39.0	36.5
Std	0.87	1.69	1.56	1.30	0.97	0.90	0.75

S/N	#12976	#18870	#18871	#22519	#22520	#24136
---	-----	-----	-----	-----	-----	-----
001	37.5	38.8	39.8	36.2	36.5	34.2
002	35.2	37.5	37.2	35.2	35.8	35.2
003	37.5	00.0	00.0	00.0	00.0	00.0
004	37.2	39.2	31.0	02.0	00.0	00.0
005	36.2	38.2	39.5	35.8	36.2	34.5
006	36.2	39.5	40.2	37.8	37.5	37.5
007	36.2	39.5	40.2	37.8	38.5	37.5
008	36.8	39.5	40.5	37.2	37.5	36.2
009	36.8	39.8	40.8	37.2	37.8	36.2
010	37.0	40.2	41.2	38.5	38.2	37.5
011	36.2	38.8	40.0	36.0	36.2	34.0
012	36.2	21.2	24.0	14.5	00.0	00.0
AVG	36.6	39.1	39.0	36.9	37.1	35.9
Std	0.64	0.76	2.87	1.04	0.92	1.37

NOTE: ALL VALUES ARE AMPERE-HOURS TO 1.0V
PRECEDED BY A 0.1C CHARGE (17+-1 HOURS)
TEST TEMPERATURE = 5+-3 DEG.C
DISCHARGE RATE = 15.00+-0.10 AMPERES

80-AH Battery Cells 50% DOD



80-AH Battery Cells 50% DOD

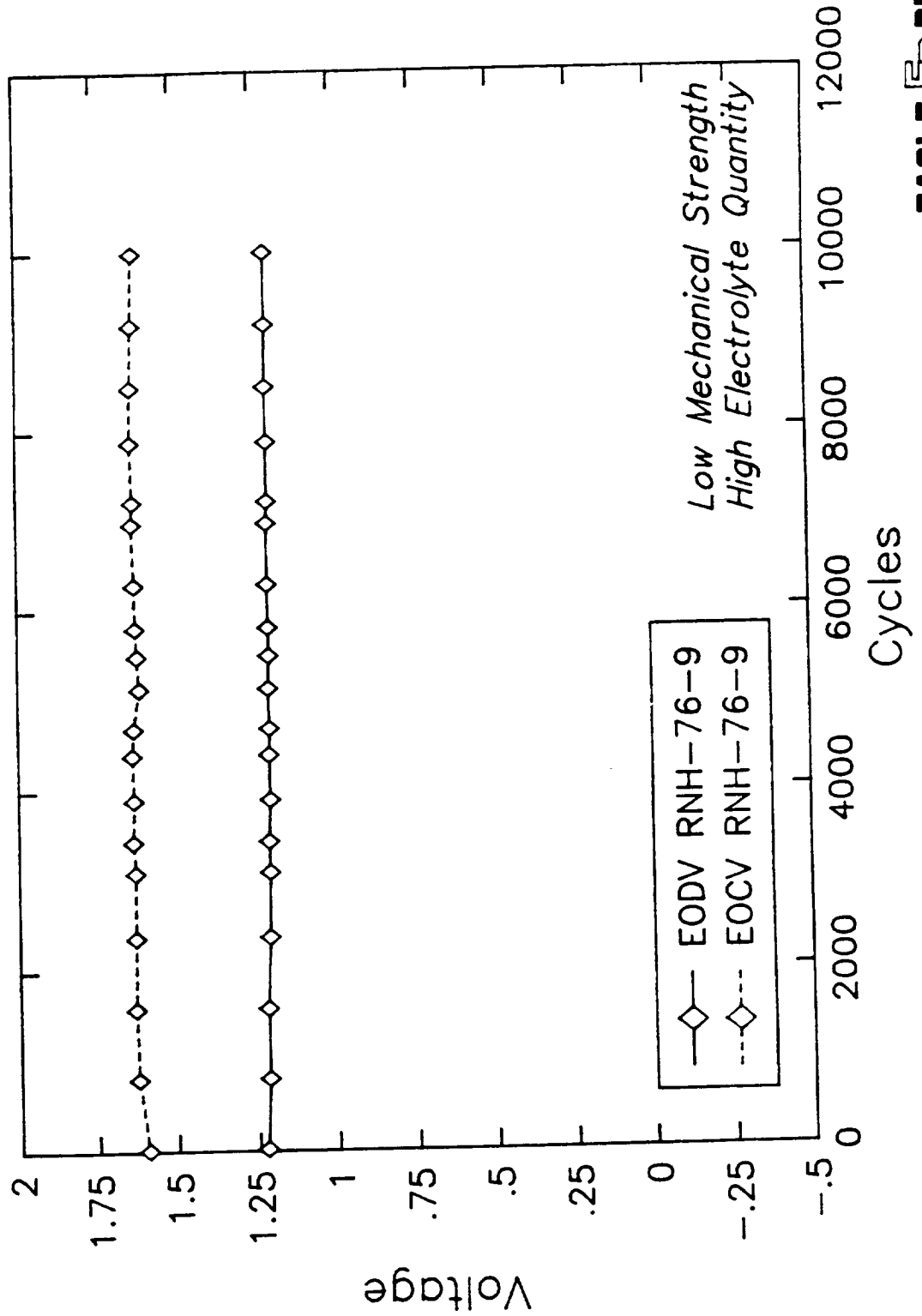


EXHIBIT #11

New NiH₂ Battery Cell Technologies

For Evaluation In LEO Life Cycle Testing

- **Fiber positive electrode sinter structure**
- **Advanced separator materials**
- **Lower electrolyte concentrations**
- **Temperature gradient sensitivity**

The Ni-H₂ Battery System:
A Space Flight Application Summary

Lee Miller
Eagle-Picher Industries, Inc. (EPI)

Abstract

It is generally accepted nickel-hydrogen will be the major rechargeable battery system selected for high-reliability, aerospace applications such as spacecraft through at least the remainder of this century. Therefore, it may be of benefit to potential aerospace users and others interested in system reliability aspects if an application summary were offered. For example, it may not be common knowledge there have been 16 satellite launches which have flown the Ni-H₂ battery system. Furthermore, these missions in total have surpassed 20,000,000 battery cell hours of space flight operation. Both of these data would be significantly greater but further launches were delayed as the results of the STS accident.

This paper will summarize the aerospace programs which have flown, are flying and will fly the Ni-H₂ battery system.

Background

The nickel-hydrogen battery design has been promoted as the most advanced, long life, rechargeable battery technology developed over the last 50 years. Per unit weight this system should offer more than twice the power available from the previously used battery system (nickel-cadmium). In the area of electrical cycle life capacity, a projected 30,000 cycle, 15 year capability (versus 10,000 - 15,000 cycles and 5-7 years for nickel-cadmium) renders a system ability to actually outlast the equipment in which it may be installed. In addition, the nickel-hydrogen battery offers a true hermetically sealed design which means it is totally maintenance free and the danger of electrolyte leakage is virtually eliminated.

This design also offers the advantage of not requiring acceptance of new electrochemical technology by the potential user. The Ni-H₂ battery cell simply combines the best features of the nickel-cadmium (Ni-Cd) system (positive electrode) and the hydrogen/oxygen (H₂/O₂) fuel cell system (H₂ electrode). A simple, common gas design evolves which features only established, and both chemically and structurally stable components (thus a high DOD and long cycle life capability), and which can operate over a wide temperature range (-20° to 40°C has been demonstrated).

The electrochemical reactions involved are straightforward and are well known within the industry. For the first time a hermetically sealed, rechargeable battery system is available which can sustain high rate overcharge and even overdischarge without short term or long term system degradation. In addition, the reactions are "H₂O" balanced which is very important from an electrolyte management stand point.

By replacing one of the two opposing metal electrodes (conventional internal battery cell design) with hydrogen gas, significant system benefits are achieved. The weight of the replaced metal electrodes are of course eliminated plus overall system performance is enhanced. The potential for metal-to-metal shorting is minimized and the lack of a "wear-out" mechanism for a gas reaction greatly improves system cycle life capability. The nickel-hydrogen battery system has already demonstrated an abuse tolerance (both operational and environmental) far in excess of any competitive battery and this simply translates into superior system reliability.

Because of this inherent reliability, the nickel-hydrogen system has been initially designed and produced for "high rel" aerospace applications. To the extent this technology has been, is now and will be applied in this industry is the subject of this paper.

Space Flight Application Summary

The subject flight programs will be summarized under four (4) categories as follows.

- I. Programs Which Have Flown
These programs are now complete.
- II. Programs Which Are Flying
These programs have satellites now in operation and may have additional launches scheduled.
- III. Programs Which Will Fly
These programs are in the hardware production phase, but no launch has occurred as of this date.
- IV. Programs Which Plan to Fly

These programs are committed to or are seriously considering the application of the Ni-H₂ battery system.

To facilitate a review of this information, the associated data will be presented in a tabular format under the above headings. The program will be identified and pertinent details listed.

Although EPI, in its role as a battery and a battery cell manufacturer, has some general program level knowledge, a few program detail errors may occur. We are obliged to apologize in advance if this is the case.

I. Programs Which Have Flown:

1. USAF "Flight Experiment"

- a) Prime Contractor - LMSC
- b) Mission - LEO
- c) Duration - approximately one (1) year
- d) Battery Capacity - 50 Ahr
- e) Battery Size - 21 cells
- f) Launch Date - 1976

2. US Navy "NTS-2 Satellite"

- a) Prime Contractor - TRW/Comsat
- b) Mission - High altitude polar,
similar to accelerated GEO
- c) Duration - approximately eight (8) years
- d) Battery Capacity - 35 Ahr
- e) Battery Size - Two (2) 7 cell modules
connected in series
- f) Launch Date - 1976

II. Programs Which Are Flying:

3. "Intelsat V"

- a) Prime Contractor - FACC
- b) Mission - GEO
- c) Duration - Longest, five (5) years now
- d) Battery Capacity - 30 Ahr
- e) Battery Size - 27 cells
- f) Launch Date - 1983 (2), 1984 (1),
1985 (3), 1986 (1)

4. "Spacenet"

- a) Prime Contractor - RCA
- b) Mission - GEO
- c) Duration - Longest, four (4) years now
- d) Battery Capacity - 40 Ahr
- e) Battery Size - Two (2) 11 cell modules
connected in series
- f) Launch Date - 1984 (2)

5. "G-Star"

- a) Prime Contractor - RCA
- b) Mission - GEO
- c) Duration - Longest, three (3) years now
- d) Battery Capacity - 30 Ahr
- e) Battery Size - Two (2) 11 cell modules
connected in series
- f) Launch Date - 1985 (1), 1986 (1)

6. "American Sat"

- a) Prime Contractor - RCA
- b) Mission - GEO
- c) Duration - Three (3) years now
- d) Battery Capacity - 35 Ahr
- e) Battery Size - Two (2) 11 cell modules
connected in series
- f) Launch Date - 1985

7. "Sat Com K"

- a) Prime Contractor - RCA
- b) Mission - GEO
- c) Duration - Longest, three (3) years now
- d) Battery Capacity - 50 Ahr
- e) Battery Size - Two (2) 11 cell modules
connected in series
- f) Launch Date - 1985 (1), 1986 (1)

III. Programs Which Will Fly:

8. "Olympus"

- a) Prime Contractor - BAe (UK)
- b) Mission - GEO
- c) Duration - 10 year requirement
- d) Battery Capacity - 35 Ahr
- e) Battery Size - 31 cells
- f) Launch Date - First projected 1989

9. "Intelsat VI"

- a) Prime Contractor - HAC
- b) Mission - GEO
- c) Duration - 10 year requirement
- d) Battery Capacity - 44 Ahr
- e) Battery Size - Two (2) 16 cell modules
connected in series
- f) Launch Date - First projected 1989

10. "Military Satellite"

Detailed information on these type applications is classified.

11. "Milstar"

- a) Prime Contractor - LMSC
- b) Mission - Multiple orbits
- c) Duration - 10 year requirement
- d) Battery Capacity - 76 Ahr
- e) Battery Size - 22 cells
- f) Launch Date - First projected 1990

12. "Italsat"

- a) Prime Contractor - FACC
- b) Mission - GEO
- c) Duration - 10 year requirement
- d) Battery Capacity - 30 Ahr
- e) Battery Size - 27 cells
- f) Launch Date - First projected 1989

13. "SCS-1"

- a) Prime Contractor - FACC
- b) Mission - GEO
- c) Duration - 15 year requirement
- d) Battery Capacity - 83 Ahr
- e) Battery Size - 27 cell
- f) Launch Date - First projected 1989

14. "Space Telescope (ST)"

- a) Prime Contractor - LMSC
- b) Mission - LEO
- c) Duration - Five (5) year requirement
- d) Battery Capacity - 90 Ahr
- e) Battery Size - 23 cells
- f) Launch Date - First projected 1990

15. "HBO Satellite"

- a) Prime Contractor - RCA
- b) Mission - GEO
- c) Duration - 10 year requirement
- d) Battery Capacity - 50 Ahr
- e) Battery Size - Two (2) 11 cell modules
connected in series
- f) Launch Date - First projected 1989

16. "Anik-E Satellite"

- a) Prime Contractor - Spar/RCA
- b) Mission - GEO
- c) Duration - 12 year requirement
- d) Battery Capacity - 50 Ahr
- e) Battery Size - Two (2) 11 cell modules
connected in series
- f) Launch Date - First projected 1989

17. "TV-Sat 2"

- a) Prime Contractor - MBB/AEG (Germany)
- b) Mission - GEO
- c) Duration - 10 year requirement
- d) Battery Capacity - 30 Ahr
- e) Battery Size - 27 cells
- f) Launch Date - First projected 1988

18. "Eutelsat II"

- a) Prime Contractor - ASCA (France)
- b) Mission - GEO
- c) Duration - 10 year requirement
- d) Battery Capacity - 65 Ahr
- e) Battery Size - 27 cells
- f) Launch Date - First Projected 1989

19. "Military Satellite"
Detailed information on these type applications
is classified.

20. "Telecom 2"

- a) Prime Contractor - Matra (France)
- b) Mission - GEO
- c) Duration - 10 year requirement
- d) Battery Capacity - 78 Ahr
- e) Battery Size - 27 cells
- f) Launch Date - First projected 1990

V. Programs Which Plan to Fly

21. "Space Station"

- a) Prime Contractor - FACC
(Power Subsystem)
- b) Mission - LEO
- c) Duration - 6.5 year requirement
- d) Battery Capacity - 81 Ahr
- e) Battery Size - 30 cells
- f) Launch Date - Mid 1990's

22. "Columbus" (European Space Station)

- a) Prime Contractor - AEG (Germany)
- b) Mission - LEO
- c) Duration - N/A
- d) Battery Capacity - N/A
- e) Battery Size - N/A
- f) Launch Date - Mid 1990's

23. "SAX Satellite"

- a) Prime Contractor - FIAR (Italy)
- b) Mission - LEO
- c) Duration - Four (4) year requirement
- d) Battery Capacity - 30 Ahr
- e) Battery Size - 29 cells
- f) Launch Date - First projected 1990

NOTE: For the remaining applications under this category, we are not certain the prime contractor has been selected as of this date. The proposed detail program information which has been provided to EPI varies between prime contractors. It would not be appropriate to publish this information and only the program name and mission will be identified.

24. "Olympus" Follow On
b) Mission - GEO

25. "Italsat" Follow On
b) Mission - GEO

26. "UHF" Follow On
b) Mission - LEO

27. "X-Ray Telescope"
b) Mission - LEO

28. "Intelsat VII"
b) Mission - GEO

29. "Aussat B"
b) Mission - GEO

30. "GPS Block IIR"
b) Mission - GEO

31. "Inmarsat II"
b) Mission - LEO
32. "Super Program"
b) Mission - Multiple orbits
33. "Military Satellites"

At this time a total of six (6) programs are qualified for classification under this category.

Conclusion

This limited review has identified 38 programs which have, are or will likely constitute the application base for this battery technology. It is hoped this summary will provide a useful reference for potential users and others who may be interested in the extent of the application of the nickel-hydrogen battery system.



NICKEL HYDROGEN BATTERY DIODE BYPASS CIRCUIT TEST

Michael J. Mackowski

**Presented by
Ken Schwer**

**November 1988
NASA GSFC Battery Workshop**

McDonnell Douglas Astronautics Company - Missile and Defense Electronics Division

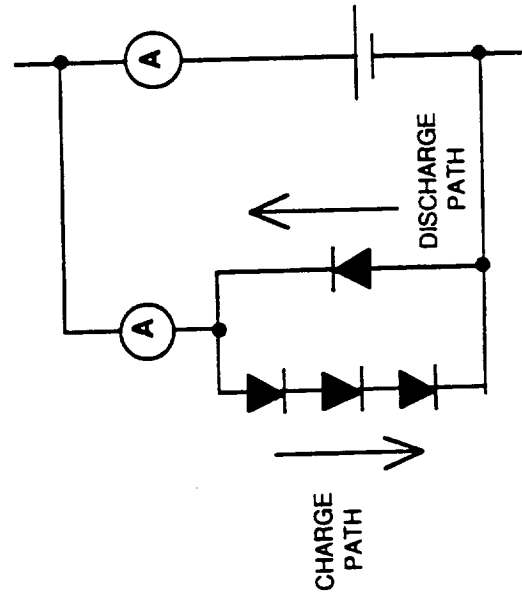


PURPOSE OF TEST

- To characterize the behavior of a NiH2 battery with a failed cell protected by a diode bypass circuit.
- To evaluate the hardware required to implement a diode bypass circuit for a low Earth orbit battery.

TEST CIRCUIT

- A bypass circuit was installed across one cell of a 19-cell (originally 21-cell) prototype battery.
- Three diodes are required in series in the forward direction to prevent current flow during normal charge operation.
- One diode is needed in the reverse path to prevent current flow during normal discharge operation.



NOTE:
EACH DIODE
RATED FOR
75 AMPS



TEST PROCEDURES

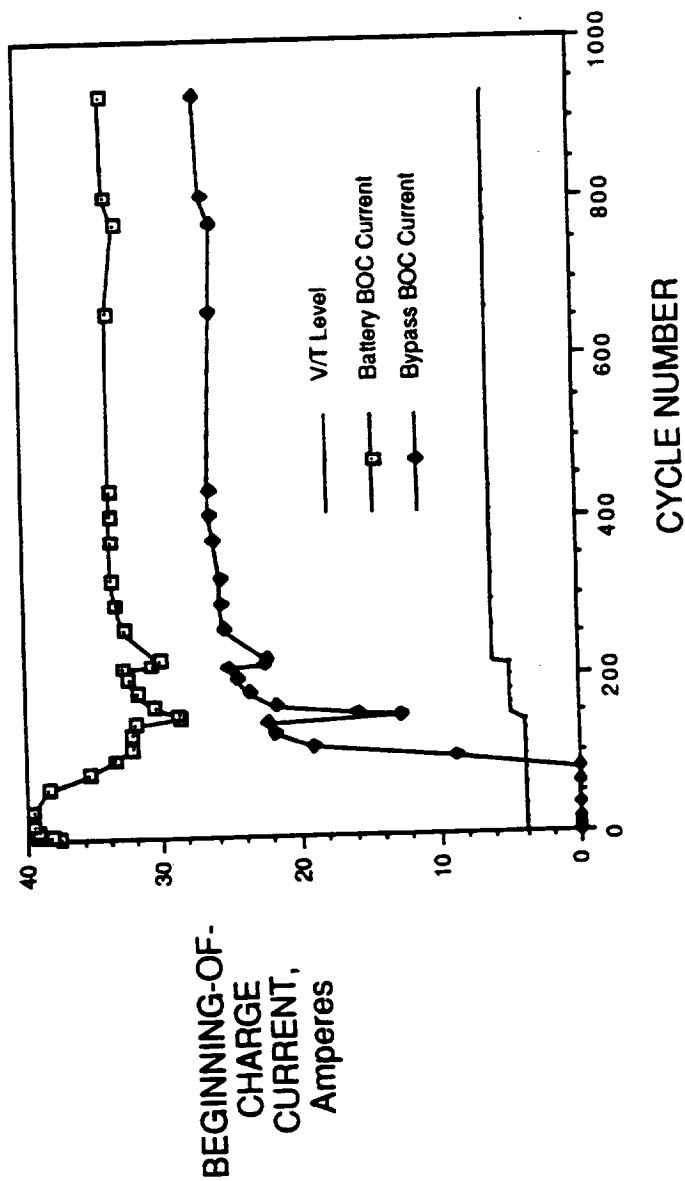
- The prototype battery had been stored for eleven months.
- A recharge and 79 cycles showed that it was in usable condition (38 Ah measured capacity).
- The fill tube of one cell was cut off and allowed to vent.
- After 90 cycles (10 Ah discharge each), the voltage across the test cell was sufficient to turn on the bypass diodes (both directions)



EFFECTS ON BATTERY OPERATION

- With a high internal resistance, the test cell had a disproportionate share of the battery voltage. This resulted in the other cells being undercharged.
- The V/T charge level was then increased two levels.
- To an outside observer (i.e., ground controller), this would be the only indication of a problem, unless individual cells or bypass circuits were monitored.

BYPASS CURRENT COMPARED TO TOTAL BATTERY CURRENT AND V/T CHARGE LEVEL





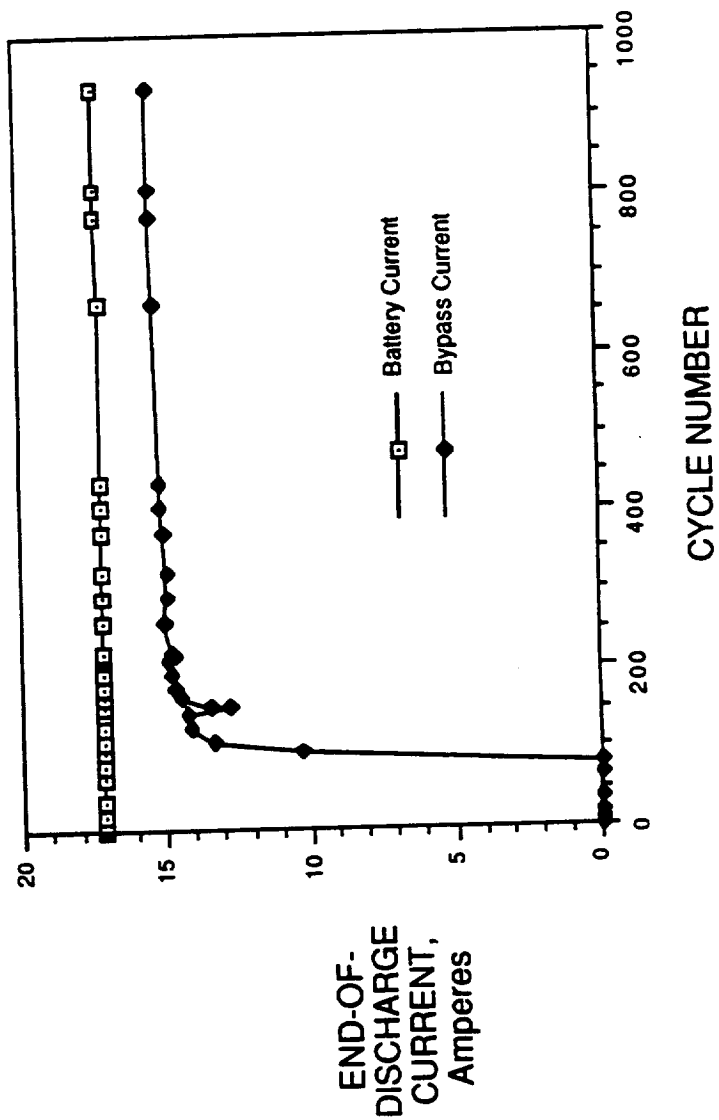
CELL DRY-OUT

- After about 300 cycles, no additional current was going through the bypass circuits.
- At the end of the test, bypass currents were:
 - 89% of the total discharge current
 - 78% of the total charge current
- Had a vacuum test been performed, these levels would have been reached much sooner, and probably exceeded.
- The test was terminated after 933 cycles.

C-4



BYPASS CURRENT COMPARED TO TOTAL BATTERY CURRENT





CONCLUSIONS

- With individual cell bypass circuits installed, it will be difficult to discriminate a simple "sick" cell from a completely failed, open-circuited cell, using typical telemetry parameters.
- Bypass circuits, using 75-ampere-rated diodes, on low Earth orbit nickel hydrogen batteries, could add over one pound per cell. There are other significant impacts to the battery's thermal and mechanical design.
- Because of the above items and the lack of reported open-circuit cell failures, we do not recommend incorporating bypass circuits in LEO NiH2 batteries.



POWER TECHNOLOGY DIVISION



Lewis Research Center

IMPEDANCE CHARACTERISTICS OF Ni ELECTRODES
FROM DIFFERENT MANUFACTURERS

DR. MARGARET A. REID
NASA LEWIS RESEARCH CENTER

GODDARD BATTERY WORKSHOP
NOVEMBER 2, 1988

GOAL OF IMPEDANCE STUDIES

TO UNDERSTAND WHAT IS HAPPENING AS THE ELECTRODE IS CYCLED AND WHEN THE ELECTRODE UNDERGOES OVERCHARGE, OVERDISCHARGE, AND STORAGE

TO DEVELOP AN ACCEPTANCE TEST THAT WILL PREDICT AT THE TIME OF CELL ACTIVATION WHETHER THE GOALS OF LIFE AND PERFORMANCE WILL BE MET BY A GIVEN CELL

TEST ITEMS UNDER STUDY

FLIGHTWEIGHT CELLS

BOILER PLATE CELLS

HALF-CELLS WITH LIGHTWEIGHT ELECTRODES

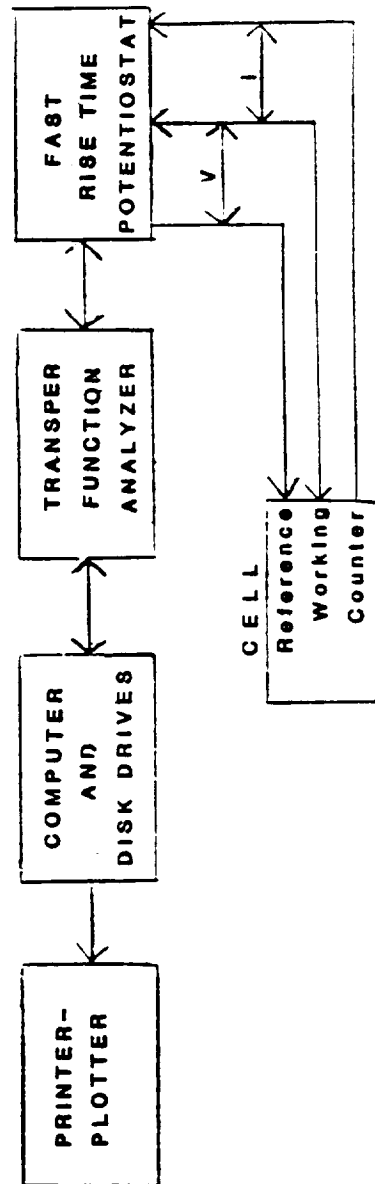
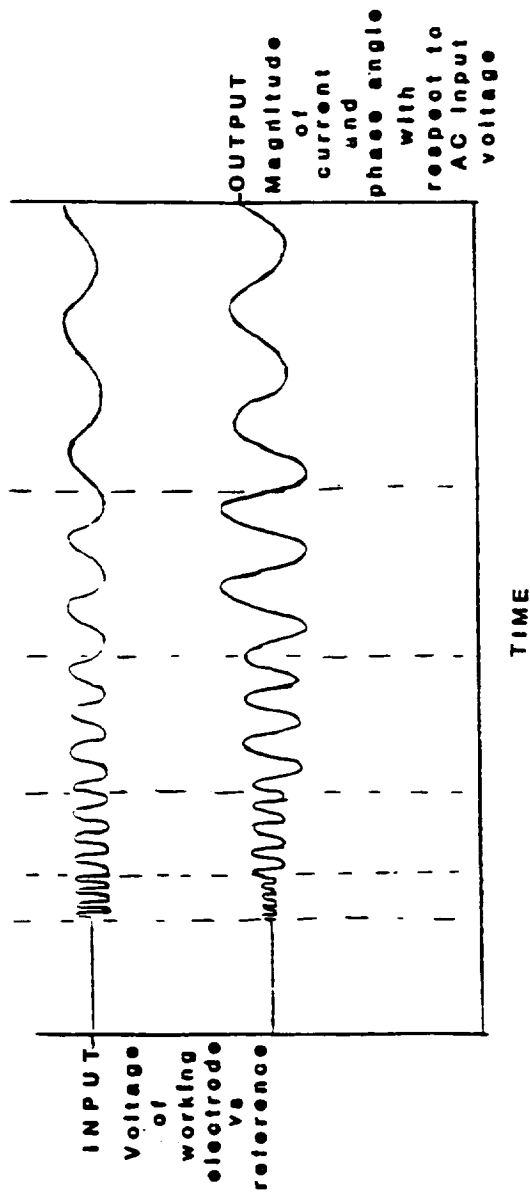
BIPOLAR CELLS

ELECTRODES FOR STUDYING CAPACITY LOSS ON STORAGE

IF THE CELL CAN BE CONSIDERED TO BE AN ASSEMBLY OF RESISTORS, CAPACITORS, AND INDUCTORS, THE VALUES OF THESE COMPONENTS CAN BE DETERMINED, ALTHOUGH NOT UNIQUELY, BY MEASURING THE IMPEDANCE OF THE CIRCUIT OVER A WIDE RANGE OF FREQUENCIES, USUALLY AT LEAST FIVE TO SIX DECADES.

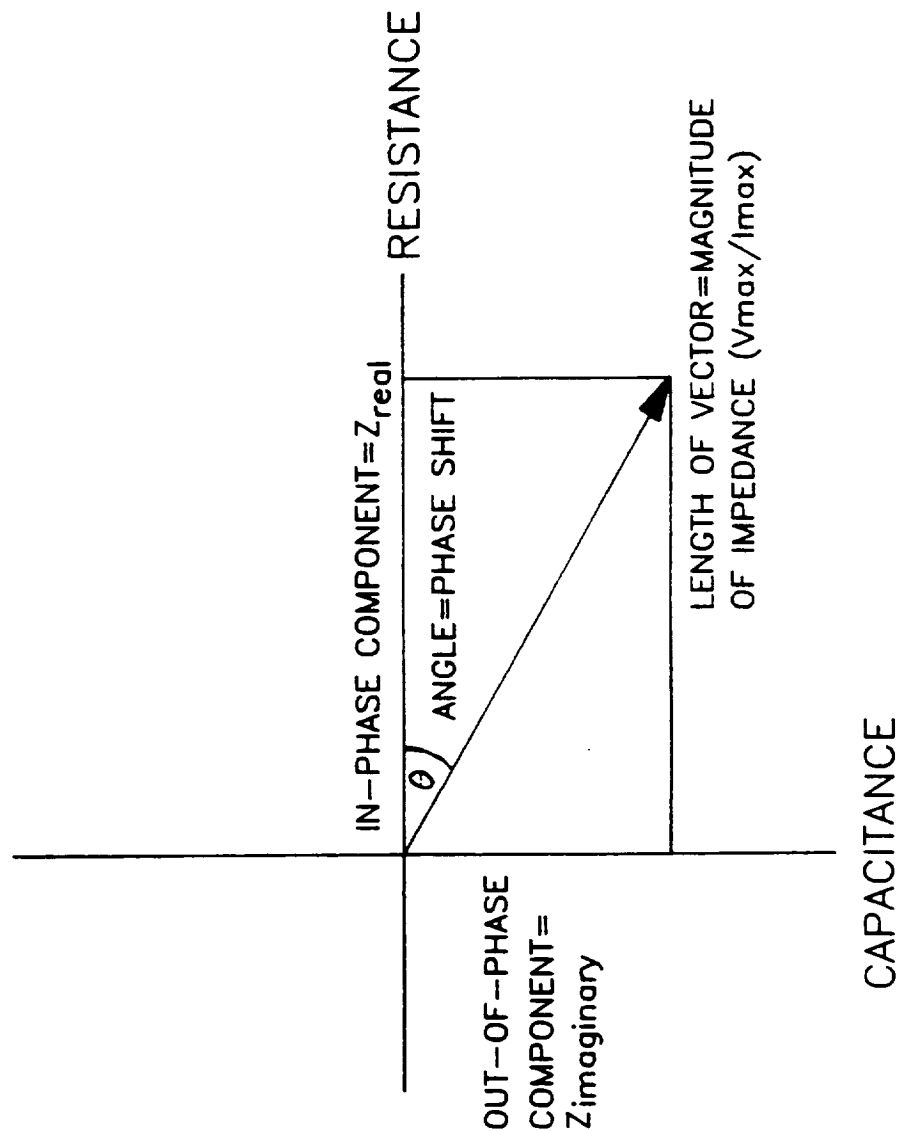
MODERN, SOPHISTICATED, COMPUTER CONTROLLED EQUIPMENT CAN MEASURE IMPEDANCES ACCURATELY OVER A WIDE RANGE OF FREQUENCIES AND SIGNAL MAGNITUDES. THE TECHNIQUE IS NON-DESTRUCTIVE AND CAN BE USED FOR ELECTRODES OF SIZES RANGING FROM SUB-MILLIMETER DIMENSIONS TO FULL SCALE BATTERIES UP TO OVER 100 A-H CAPACITY,

ELECTRICAL COMPONENTS OF IMPEDANCE SETUP



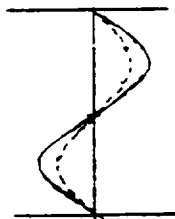
VECTOR REPRESENTATION OF IMPEDANCE AND DETERMINATION OF Z_{real} AND $Z_{imaginary}$

INDUCTANCE

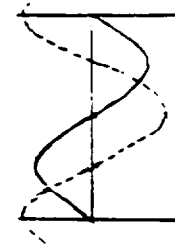


SIMPLE IMPEDANCE NETWORKS

RESISTOR



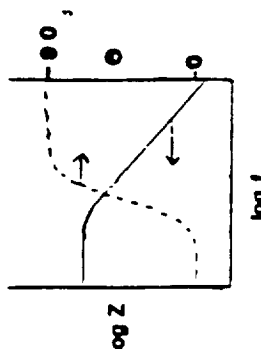
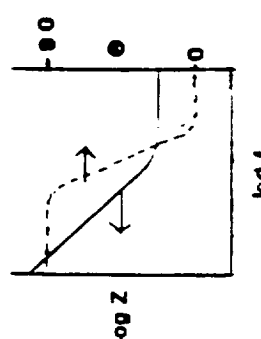
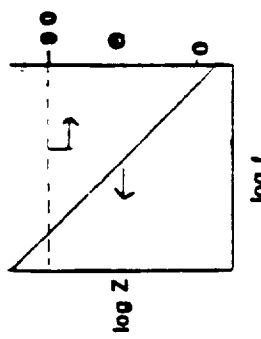
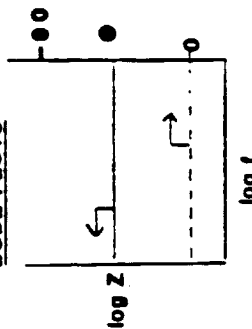
CAPACITOR



SERIES

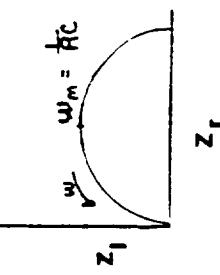
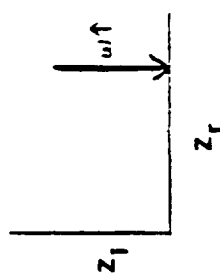
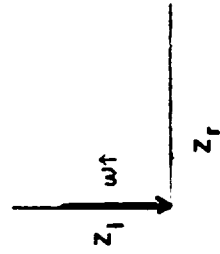
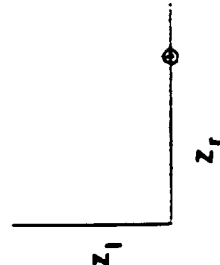


BODE PLOTS



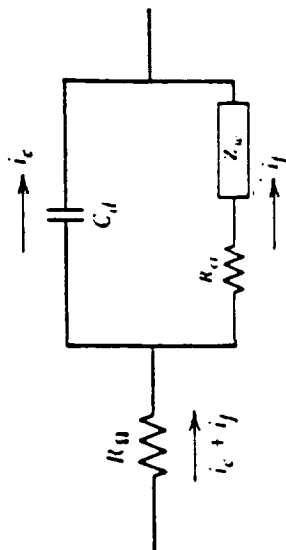
Relationship between current and voltage dependent on frequency

COMPLEX PLANE PLOTS

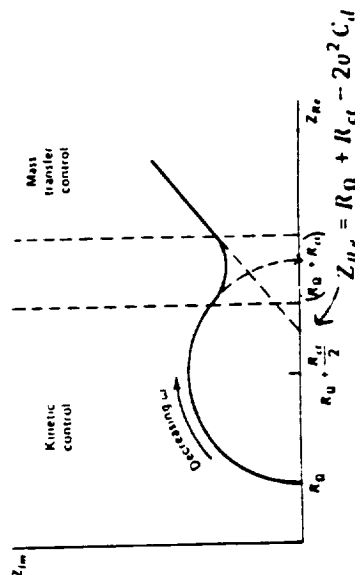


Other ways to express Impedance- Randles, Complex capacitance, Admittance, etc.

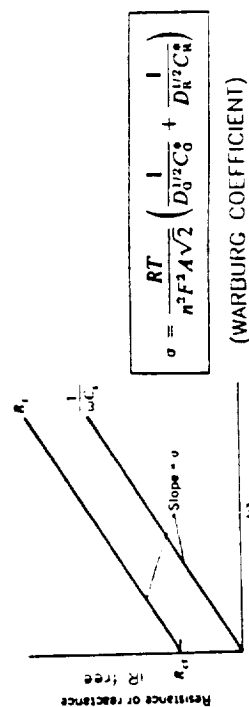
SIMPLE CIRCUIT FOR A SINGLE ELECTRODE INCLUDING DIFFUSION IMPEDANCE Z_w (WARBURG IMPEDANCE)



COMPLEX PLANE PLOT FOR ABOVE CIRCUIT

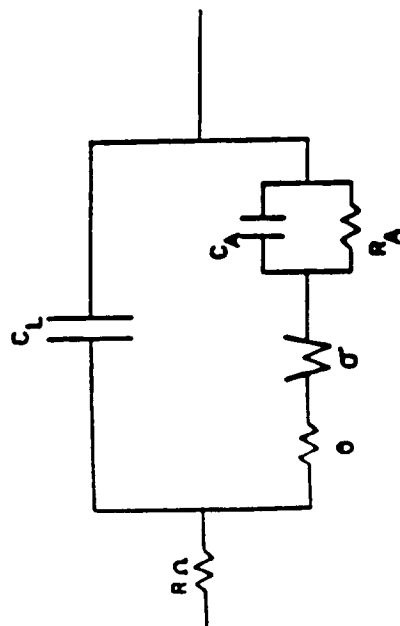
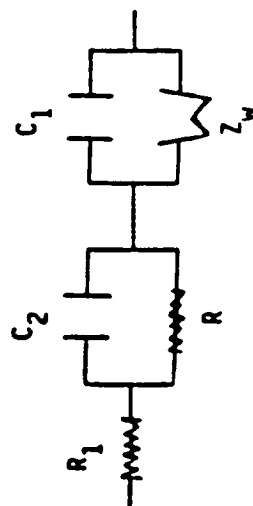


WARBURG PLOTS FOR ABOVE CIRCUIT

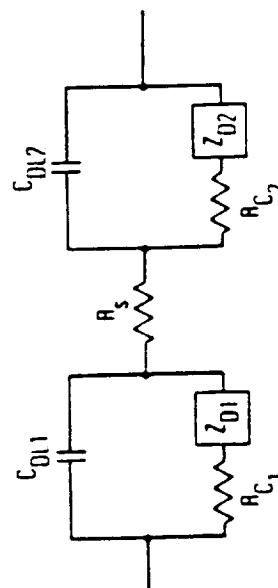


OTHER METHODS OF PLOTTING DATA CAN BE USED, FOR EXAMPLE, CAPACITANCE PLOTS

ALTERNATIVE CIRCUITS FOR A SINGLE ELECTRODE



SIMPLE CIRCUIT FOR A COMPLETE CELL





ASSEMBLED TO COMBINE WITH QUALITY

POWER TECHNOLOGY DIVISION



IMPEDANCE MEASUREMENTS ON ELECTRODES FOR STORAGE EXPERIMENT

ELECTRODES:

3-1/2" PINEAPPLE SLICE, 42.9 SQUARE CM, TRIPLICATE SAMPLES

TEST REGIME:

FORMATION CYCLES - 5 CYCLES AT C/10 CHARGE FOR

16 HRS, C/5 DISCHARGE TO 1.0 V VS AMALGAMATED ZN

CAPACITY CYCLES - 5 CYCLES AT C/2 CHARGE FOR 1 HR

PLUS 10% OVERCHARGE, DISCHARGE AT C/4 TO

1.0 V VS AMALGAMATED ZN

IMPEDANCE TESTS:

EQUILIBRATE FOR 1 HR AT 0.2 V VS Hg/HgO, MEASURE

CHARGE 20%, HOLD AT 0.4 V FOR 1 HR, MEASURE

STORE 28 DAYS UNDER VARIOUS CONDITIONS

MEASURE AT THE OCV AFTER STORAGE

DETERMINE POST STORAGE CAPACITY

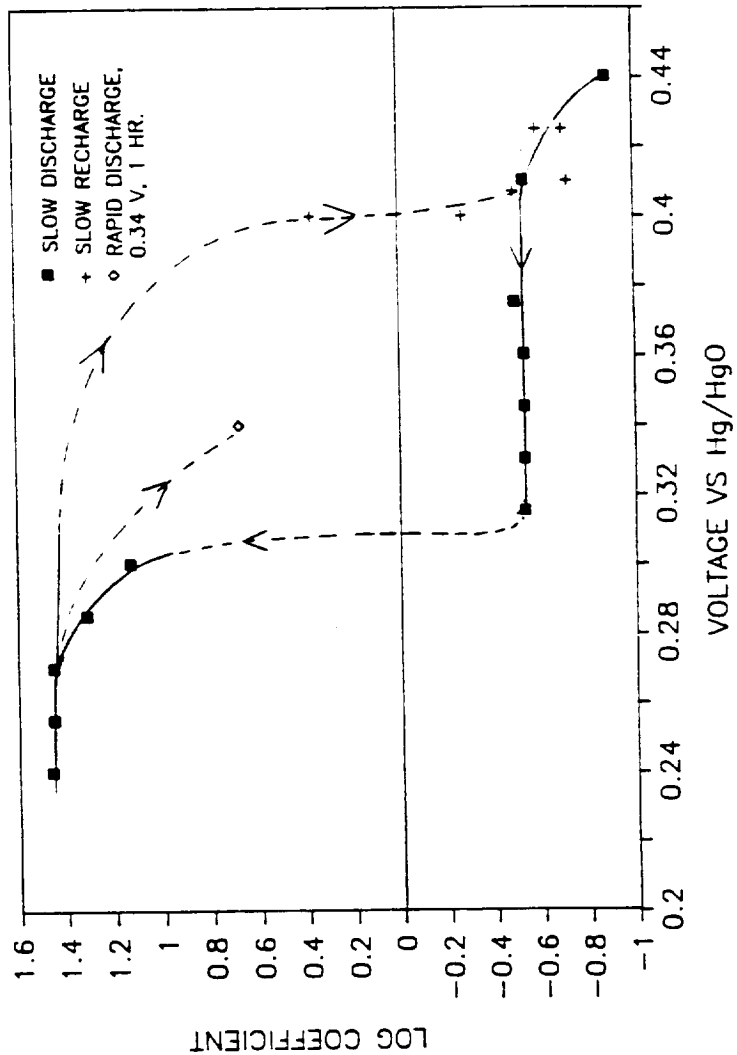
EQUILIBRATE FOR A HR AT 0.2 VS Hg/HgO, MEASURE

IMPEDANCE PARAMETERS:

1 MV SIGNAL, 5.65 HZ TO 0.0007 HZ

IMPEDANCES OF Ni ELECTRODES VARY ENORMOUSLY WITH VOLTAGE. ON THE BASIS OF MEASUREMENTS ON A CHEMICALLY IMPREGNATED ELECTRODE, IT WAS DECIDED TO MAKE MEASUREMENTS AT 0.4 V AND 0.2 V VS Hg/HgO

WARBURG COEFFICIENT OF CHEMICALLY IMPREGNATED ELECTRODE





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THE DATA PRESENTED HERE ARE
PRELIMINARY AND SHOULD NOT BE
USED TO JUDGE THE MERITS OR FAULTS
OF ANY PARTICULAR MANUFACTURING
PROCESS OR ELECTROLYTE CONCENTRATION



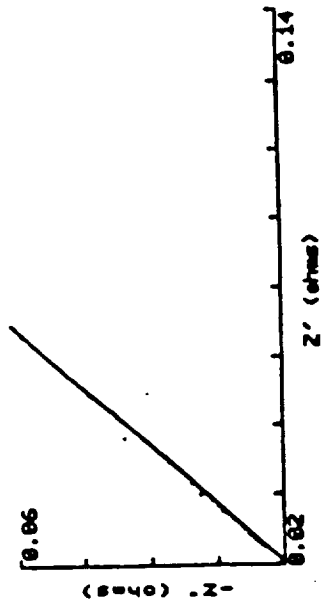
AIR FORCE RESEARCH AND DEVELOPMENT

POWER TECHNOLOGY DIVISION

NASA

Lewis Research Center

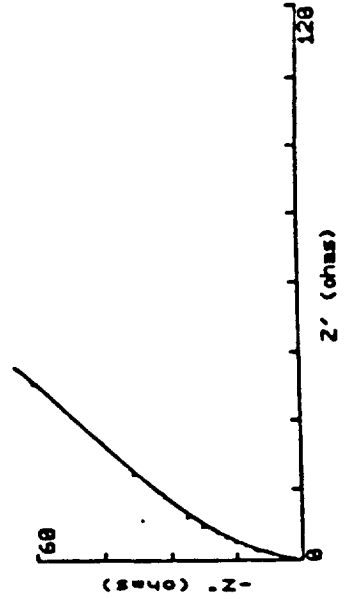
Impedance of typical
electrochemically impregnated
electrode at 0.400 V vs Hg/HgO.



Impedance of typical
electrochemically impregnated
electrode at 0.200 V vs Hg/HgO.



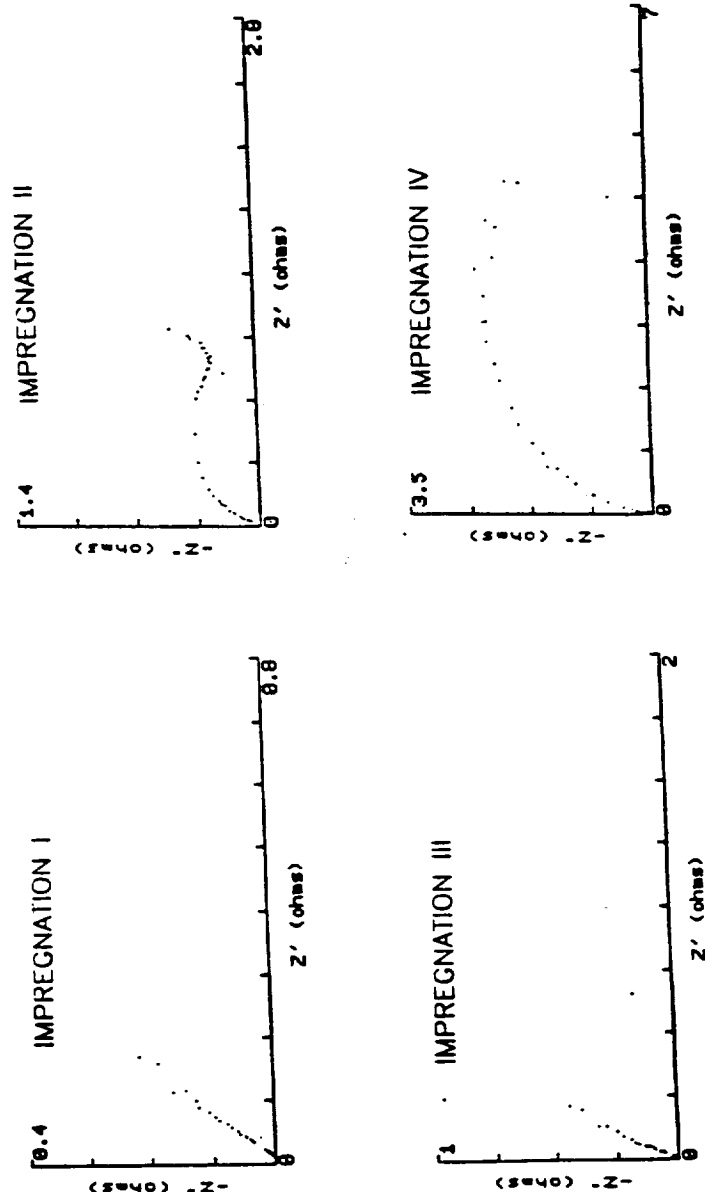
Impedance of typical
electrochemically impregnated
electrode at 0.050 V vs Hg/HgO.



IMPEDANCE PLOTS OF FOUR TYPES OF ELECTRODES

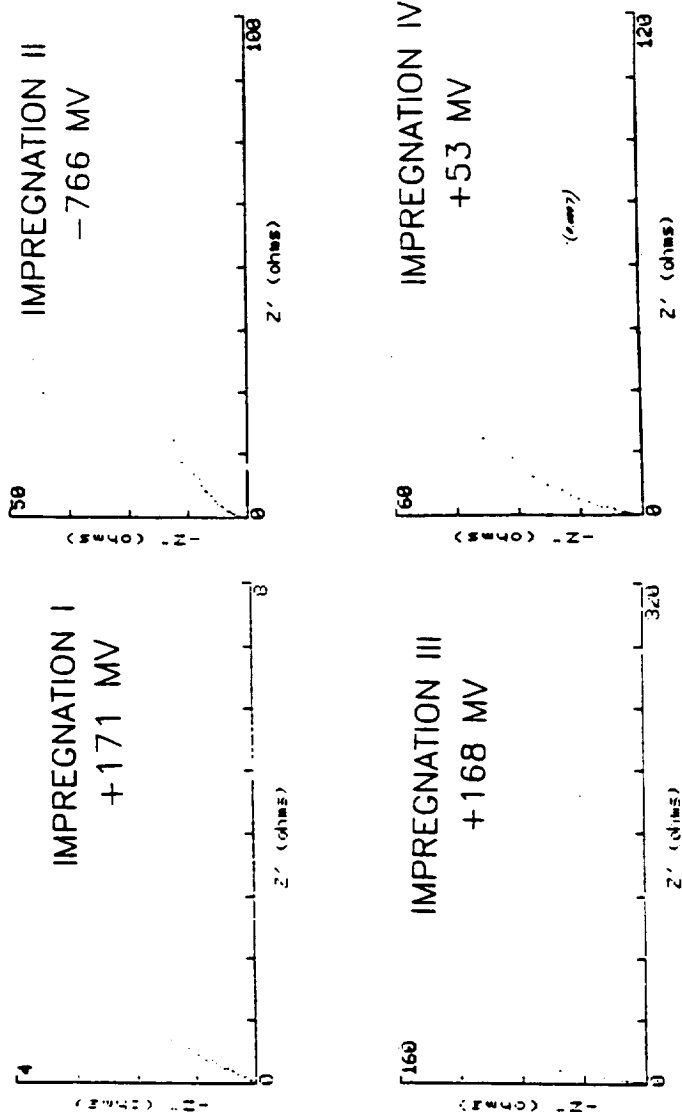
0.200V vs Hg/HgO, 31% KOH

A CHARACTERISTIC CURVE IS OBTAINED FOR EACH MANUFACTURER.



IMPEDANCES OF ELECTRODES AT 0.4 V WERE SIMILAR AND COULD NOT BE DIFFERENTIATED WITH THE EQUIPMENT USED. NEW EQUIPMENT RECENTLY RECEIVED SHOULD ALLOW DIFFERENCES TO BE MEASURED.

IMPEDANCES AND VOLTAGES VS Hg/HgO AFTER REMOVAL FROM STORAGE HIGH PRESSURE, ROOM TEMPERATURE, 31% KOH



REDUCTION BY HYDROGEN PRODUCED LOWER VOLTAGES AND
HIGHER IMPEDANCES.

VALUES TABULATED ARE THE PARALLEL RESISTANCES OBTAINED BY DRAWING THE "BEST" SEMICIRCLE ON THE NYQUIST (COMPLEX PLANE) PLOTS

STORAGE CONDITIONS ARE INDICATED AS FOLLOWS:

- HPRT31 = 500 PSI HYDROGEN, ROOM TEMP, 31% KOH
- MPRT31 = 50 PSI HYDROGEN, ROOM TEMP, 31% KOH
- LPRT31 = 1 ATM HYDROGEN, ROOM TEMP, 31% KOH
- HPLT31 = 500 PSI HYDROGEN, -20 C, 31% KOH
- HPRT26 = 500 PSI HYDROGEN, ROOM TEMP, 26% KOH

IMPEDANCES OF ALL ELECTRODES WERE GREATER AFTER STORAGE. THE HIGHER THE PRESSURE, THE LOWER THE VOLTAGE AFTER STORAGE. STORAGE AT LOW TEMPERATURES REDUCED THE AMOUNT OF VOLTAGE LOSS AND IMPEDANCE INCREASE.

THE VOLTAGE DROP AND INCREASE IN IMPEDANCE COULD BE CORRELATED QUALITATIVELY, BUT NOT QUANTITATIVELY, WITH THE MAGNITUDE OF CAPACITY LOSS ON STORAGE.

IMPEDANCE AND VOLTAGE CHANGES UPON STORAGE

HUGHES	PRE-STORAGE R	POST-STORAGE R	VOLTAGE AFTER STORAGE VS Hg/HgO
HPRT31	1.3	20.0	-0.765
MPRT31	0.9	1.0	0.186
APRT31	0.9	1.7	0.212
HPLT31	0.6	1.3	0.199
HPRT26	0.1	100.0	-0.365

YARDNEY	PRE-STORAGE R	POST-STORAGE R	VOLTAGE AFTER STORAGE VS Hg/HgO
HPRT31	0.7	77.0	0.032
MPRT31	1.8	10.2	0.191
APRT31	3.7	4.4	0.216
HPLI31	2.1	3.7	0.221
HPRT26	3.9	79.0	0.073



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POWER TECHNOLOGY DIVISION



IMPEDANCE AND VOLTAGE CHANGES UPON STORAGE

GATES	PRE-STORAGE R	POST-STORAGE R	VOLTAGE AFTER STORAGE VS Hg/HgO
HPRT31	1.0	10.6	0.170
MPRT31	1.6	3.2	0.200
APRT31	0.8	2.2	0.244
HPLI31	0.6	1.7	0.233
HPRT26	1.7	3.3	0.216

E-P	PRE-STORAGE R	POST-STORAGE R	VOLTAGE AFTER STORAGE VS Hg/HgO
HPRT31	2.1	14.0	0.173
MPRT31	2.2	3.3	0.198
APRT31	2.1	3.3	0.240
HPLI31	2.0	2.2	0.230
HPRT26	1.2	4.0	0.216



Advanced Technology Division

POWER TECHNOLOGY DIVISION



Lewis Research Center

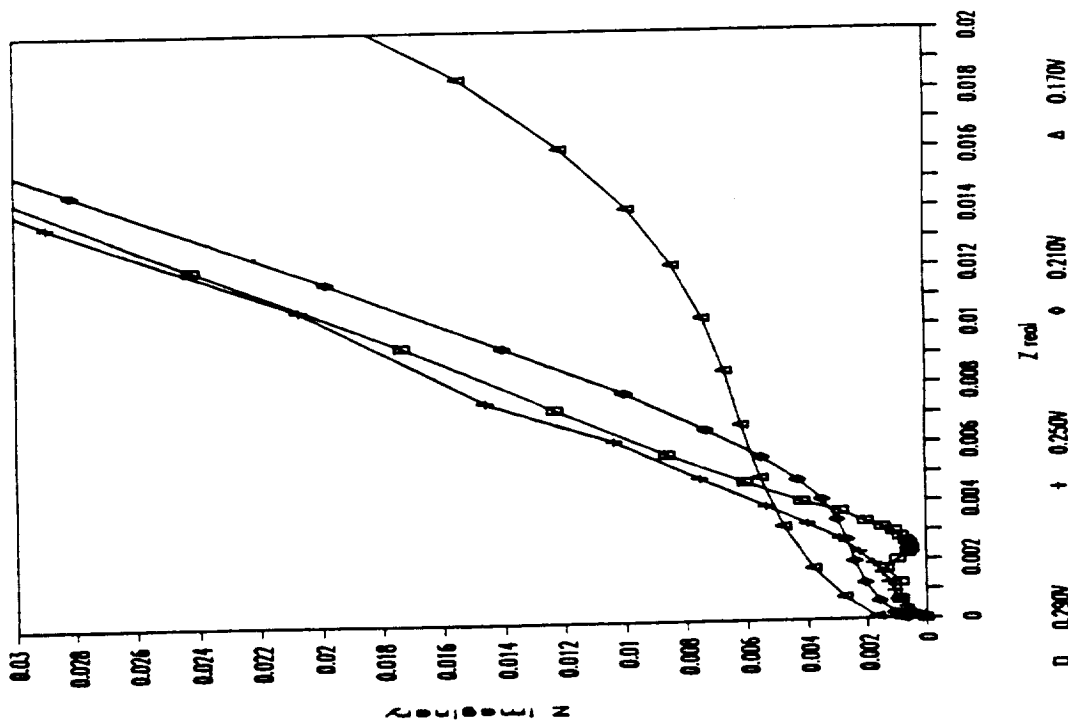
MORE COMPLETE CHARACTERIZATION OF THESE ELECTRODES IS NOW UNDER WAY WITH NEW EQUIPMENT.

EXAMPLES OF COMPLEX IMPEDANCE, WARBURG, AND COMPLEX CAPACITANCE PLOTS ARE SHOWN FOR A GATES ELECTRODE.

RESISTANCES, WARBURG SLOPES, AND CAPACITANCES VARY BY SEVERAL ORDERS OF MAGNITUDE AS VOLTAGE IS CHANGED. THE ELECTRODES FROM OTHER MANUFACTURERS HAVE SOMEWHAT DIFFERENT CHARACTERISTICS.

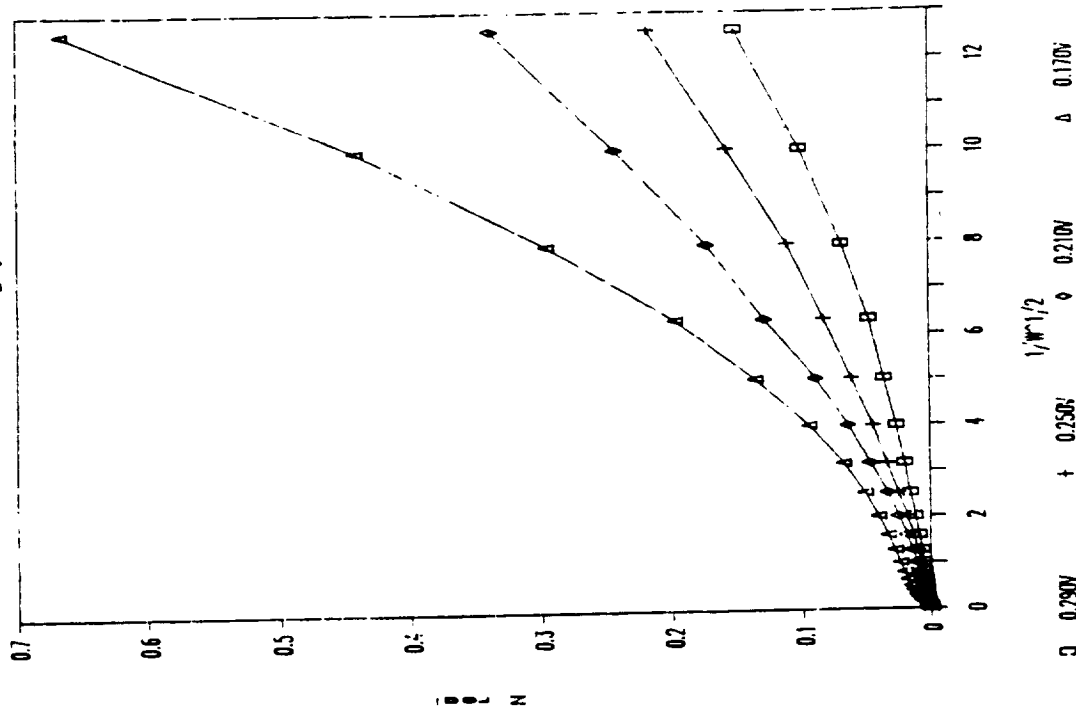
COMPLEX IMPEDANCE, HIGHER FREQUENCIES

0.250V TO 0.170V VS Hg/HgO

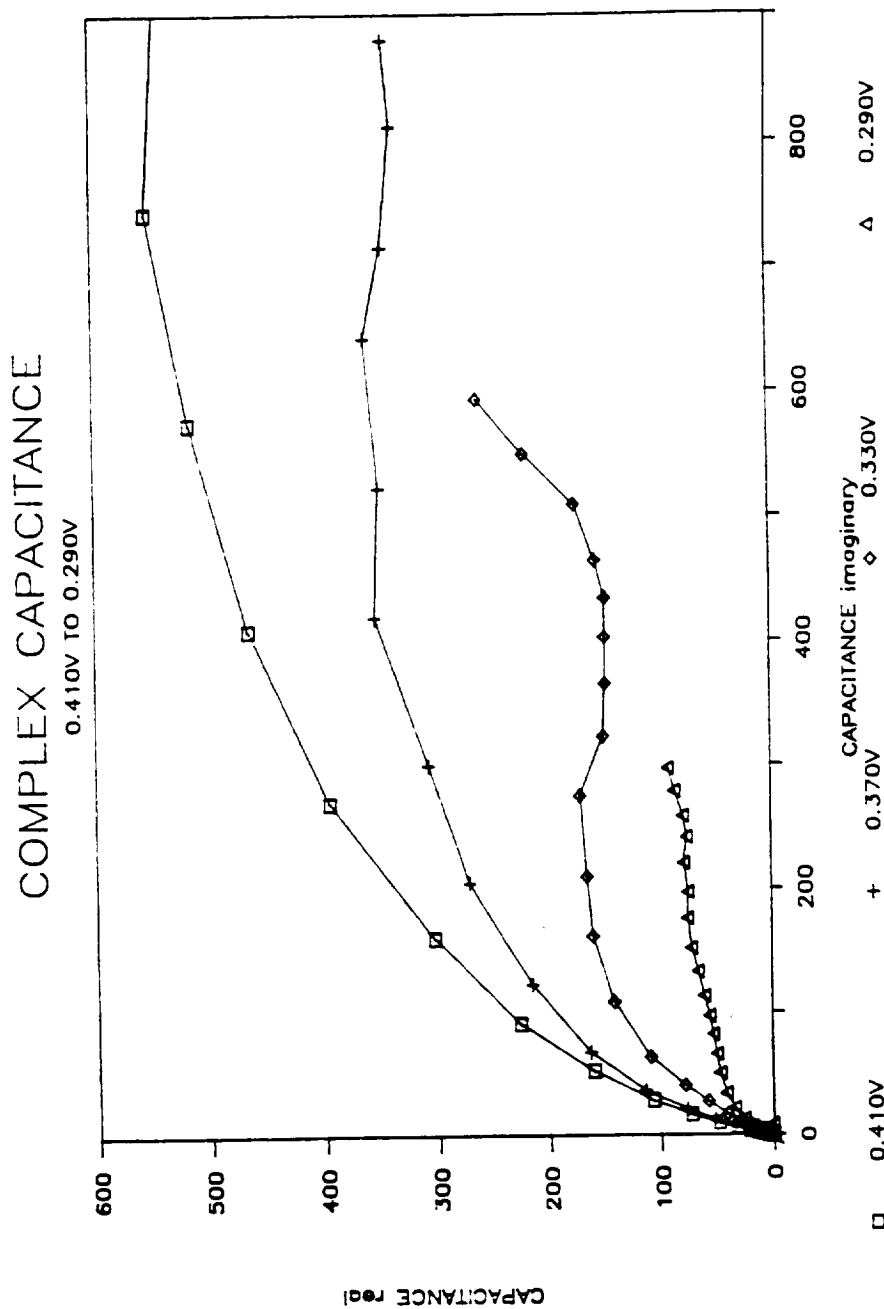


WARBURG PLOT

0.250V TO 0.170V VS Hg/HgO



TYPICAL COMPLEX CAPACITANCE PLOT FOR GATES ELECTRODE SHOWING LARGE CHANGES IN CAPACITANCE WITH VOLTAGE





FUTURE PLANS

FULLY CHARACTERIZE ELECTRODES FROM OTHER IMPREGNATION PROCESSES
CYCLE CHARACTERIZED ELECTRODES AND DETERMINE CHANGES OF PARAMETERS WITH CYCLING
MEASURE IMPEDANCES OF FULL-SIZE CELLS AS CELLS ARE CYCLED AND TRY TO CORRELATE CHANGES WITH CYCLE LIFE AND PERFORMANCE

UPDATED STATUS OF THE FRENCH NiH2 TECHNOLOGY DEVELOPMENT

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ABSTRACT

A general survey of the last French development in NiH2 technology for GEO applications is given : main results are discussed, and perspective toward future evolution presented.

INTRODUCTION

Geostationnary applications require mainly reliable and well evaluated Nickel Hydrogen technology. In Europe, that kind of power device remains of great interest, particularly in France.

Since 1985, a new development activity started under CNES control, taken place within a general search a technology plan.

NiH2 DEVELOPMENT

This development was done at SAFT, under major founding from CNES and SAFT, with the contribution of ESA. Substantial development programm was defined to respond a requirement level approved by CNES and ESA.

The purpose was to build up and evaluate a cell's definition fitted to the range 30-50 Ah in capacity, to provide power for a ten years mission.

Cell's technology developped was of the IPV type, operating at high pressure. Essential details related to this definition were presented in 1986 (ref. 1).

Conception was based on the maximum value in the range (ie 50 Ah) and basic technological components issued from SAFT background.

The choice of an individual pressure vessel, mounted into a single piece sleeve, was done assuming the fact it should permit to reach a high safety factor while offering good thermal features.

All along the program, accurate evaluation at components and cell level was done.

End of development was marked in May 1988 by a critical definition review where VHS 50 BL definition (namely 50 Ah cell) was presented and evaluation tests results largely discussed.

TESTS RESULTS

Validation test program was performed on 50 Ah cells or same sized vessels, following a schedule presented hereafter in figure 1.

Each cell or vessel tested was compliant with the same definition file and of the same manufacture and control lot.

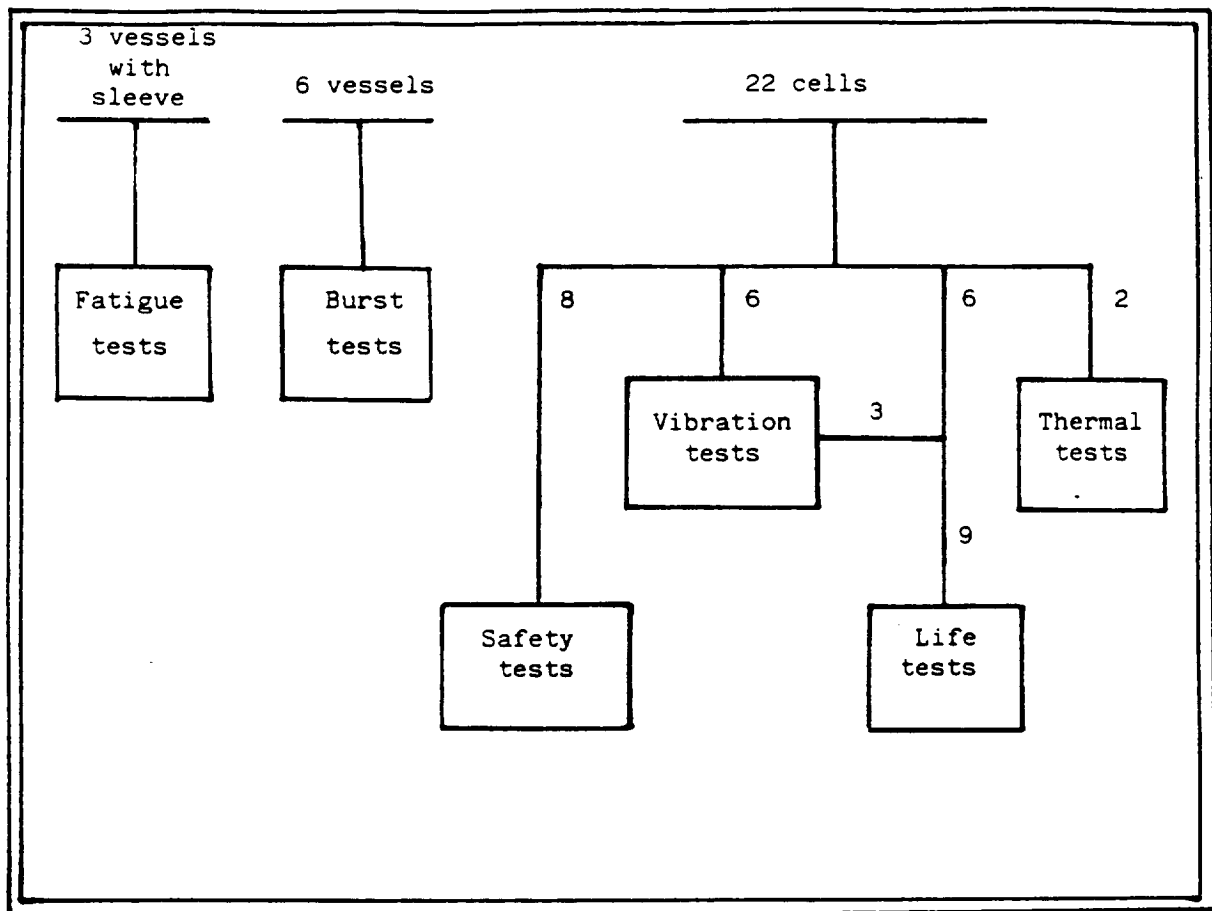


Figure 1 - Validation test plan

GENERAL CHARACTERISTICS

Based on a 22 cells lot experience. Main features for the VHS 50 BL NiH_2 cell are given hereafter in table 1.

Mean capacity at 1 V 20°C C/2	51,5 Ah
Mean energy density (at cell level)	48 Wh/kg
Mean volumic energy (at cell level)	70 Wh/l

Table 1 - VHS 50 BL characteristics

On the referenced lot, mass and capacity dispersion values were smaller than expected, which is a proof of the good manufacture control level got.

MECHANICAL TESTS

Fatigue tests

The goal of this test was to check out resistance limit of Inconel vessel design to cyclic loading, in order to simulate charge-discharge pressure variation of the structure in absence of the effect of Hydrogen.

- Conditions

- . Pressure fluid was special oil used as neutral agent for the cycling.
- . Frequency was chosen to accelerate the test and perform a large number of cycles, his value was close to 5 cycles/min.
- . Amplitude was 25-75 bars pressure range corresponding to a 100 % DOD level (75 bars being the DMOP : Design Maximum Operating Pressure).

Three vessels (each mounted into integral sleeve) were proof tested at first at 1,5 time the DMOP and then cycled under the previous conditions, and they reached more than 150 000 cycles without any damage.

Modifying the maximum pressure value up to the proof test pressure value, complementary cycling permit to get respectively for each vessel 10.000, 23.000 and 31.000 cycles more. Leakage was observed at these points. Using SEM, we have confirmed pure fatigue micro faciès and typical crack trip growth leading to leakage.

These results were in good agreement with predictive datas got previously from a mechanical rupture analysis (ESA crack computerizing mode).

Burst tests

Six naked vessels were bursted to verify the limit of the design.

- Conditions

Pressure fluids used were oil or gazeous helium and pressurization rate chosen in the application range.

Requirement level was 2,5 time the DMOP value, and for each cell this limit largely overshoted.

Such results confirmed the right vessel's design with margins good enough to take into account statistical dispersion.

Safety tests

This activity was aiming at characterize more closely safety area for this device. As a preliminary task, SAFT performed an FMECA analysis (failure mode and critical effects analysis) to define completely, cell's behaviour under functionnal aspects, hazardous events and main consequences.

Fault tree method was also employed, and this study permit to start safety tests while fixing specific conditions.

- Conditions

An overall amount of 8 cells (into sleeve) was submitted to hazardous events ; specific conditions are summarized hereafter in table 2.

Type of test	Test N°	Test conditions		
		current	temperature	time
Overcharge	1	C/S	20°C	≥ 72 H
	2	C/10	0°C	≥ 72 H
	3	C	20°C	5 H
	4	C	0°C	5 H
Over dis-charge	5	C/2	20°C	≥ 72 H
	6	C	20°C	5 H
Shock	7	Wedge impact of 25 J ont the cylindrical part of a fully charged cell		
External short circuit	8	Connetting terminals (at 20°C through an external resistance of 1,7 m Ω) of a full charged cell during 1 hour		

Table 2 - Safety test conditions

The one cell shocked, presented of course, trails of the test (de visu, at sleeve level and inside by Xray observation, at stack level). Nevertheless, it hasn't affected electrical properties as demonstrated by a follow on control.

Short circuit led to an instantaneous current higher than 8C regime. As shown in figure 2, after a transient during the first minutes there were a pseudo plateau in current at approximately 240 A with a voltage stabilization, then a sharp decrease for both electrical parameters. But after a ten minutes discharge time, current and voltage decreased slightly.

Cell's temperature measured on sleeve wall increased up to 77°C as a maximum value while pressure decreased in two steps.

Cells tested under overdischarge conditions presented a peak temperature never exceeding 40°C for a time below 1 hour, and pressure temperature and voltage reached a steady state value after 2 hours evolution as presented in figure 3.

Figure 4 compare for two cells tested under overcharge conditions respectively, at 20°C and 0°C, at a same C regime, their characteristics. Temperature effect at this kinetic of charge is not so detectable, though we can deduce from pressure behaviour the better efficiency at 20°C for the recombining reaction between O_2 and H_2 . As well as it appears at lower temperature how exothermic are the phenomenon involved during overcharge.

Main datas got from overcharge tests figured in table 3.

Test N°	Pmax (bars)	Tmax (°C)	Voltage max (V)	Capacity at 1,0 V and C/5 (Ah)
1 C/5 20°C	72,2	30,7	1,54	53,6
2 C/10 0°C	78,2	5,5	1,65	65,3
3 C 20°C	89,5	56,4	1,57	50
4 C 0°C	90,1	61,6	1,7	58,3

Table 3 - Overcharge test results

It is clear that the lower is the charge regime the best is the recombination of H_2 and O_2 because of the small amount of O_2 produced.

Others features to analyse are capacities restituted after overcharge, at lower temperature, which are higher than those in normal conditions (ie. C/2 20°C) by 10 to 25 %.

From these tests results, we can deduce that under abnormal conditions, this NiH_2 technology never presented very dangerous behaviour ; though if we should classified risky events we'd find in growing order, overdischarge, overcharge and short circuit.

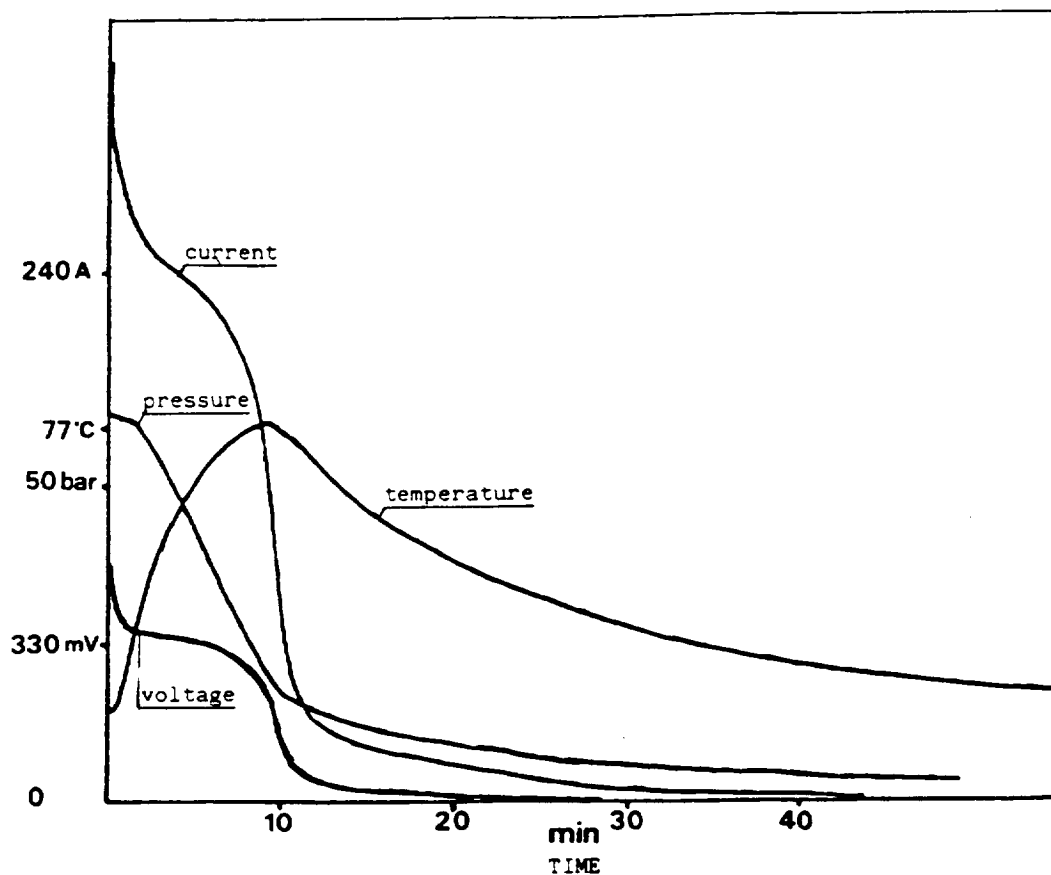
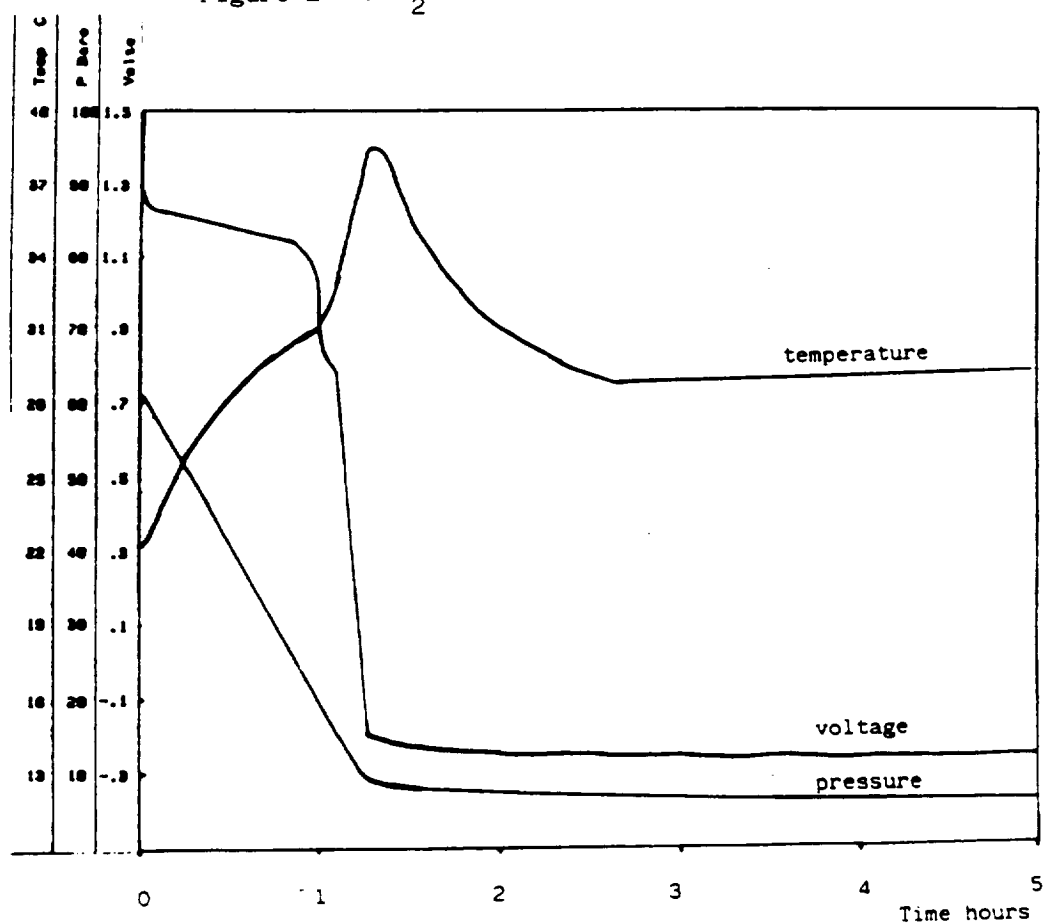


Figure 2 - NiH_2 cell short circuit characteristics



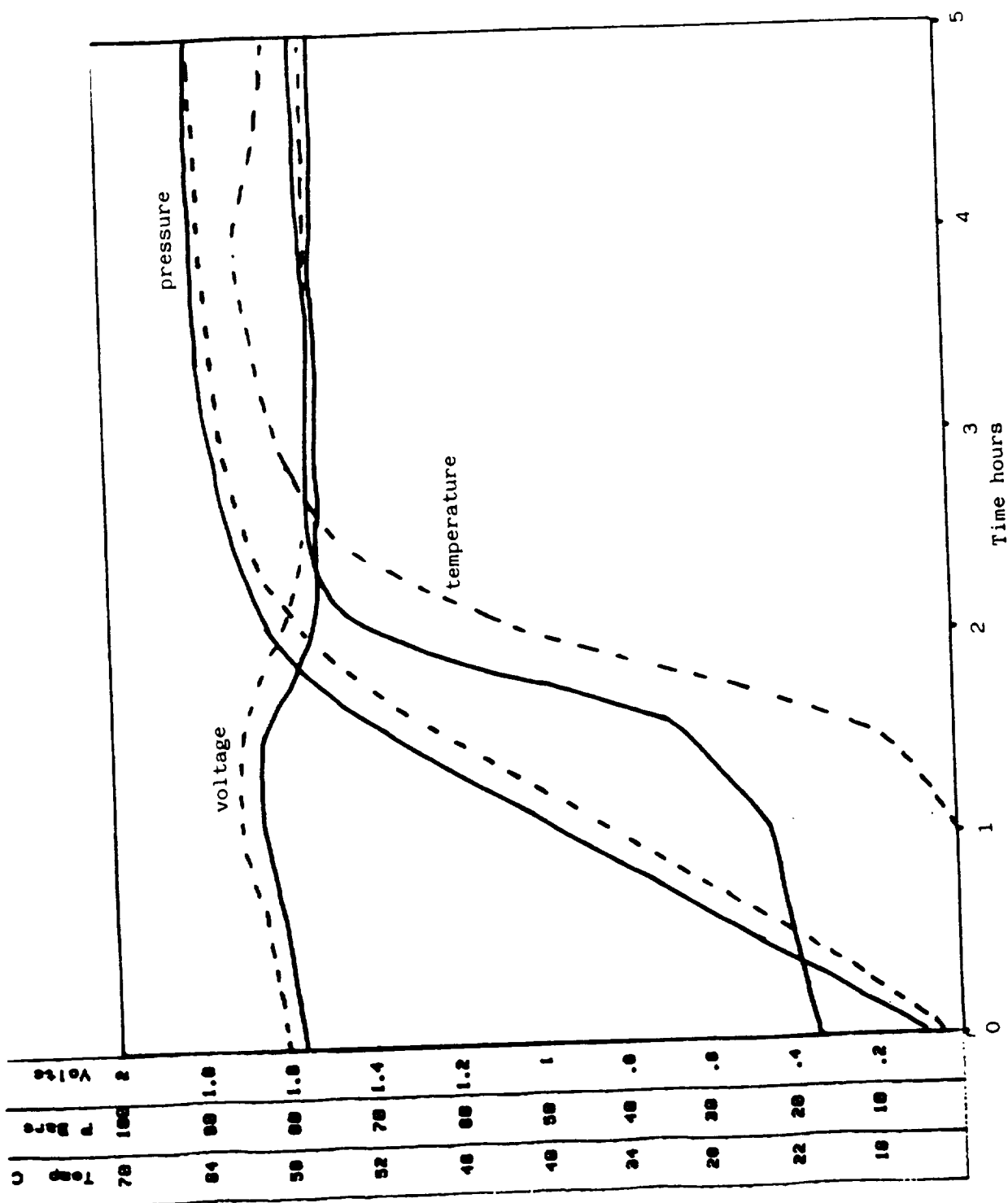


Figure 4 - NiH₂ cell overcharge characteristics at C

Thermal tests

These tests conducted under ESA contract at Aerospatiale Cannes (AS.CA), were aimed to evaluate thermal behaviour of NiH_2 50 Ah SAFT cells. In parallel, was developped by AS.CA a thermal 59 node computer model of the cell-sleeve assembly (using a SINDA program).

Two thermal prototypes instrumented as indicated in figure 5 were build up. The test was realized in thermal vacuum chamber and standard cycling conditions were C/2 discharge, C/10 charge, C/100 trickle with a DOD of 70 % and a recharge factor of 1,2. Typical curve temperature comparing two follow on cycles at node level is presented in figure 6. This original test permit to mesure instantaneous temperature and to promote a thermal cartography of the cell sleeve design to correlate the model.

Main results, in perfect agreement with predictions, are for BOL conditions (end of discharge step)

- Maximum inner temperature at stack level : 20°C
- Maximum inner gradient between stack and vessel : $6,8^\circ\text{C}$
- Mean conduction gradient along the sleeve : $< 2^\circ\text{C}$

Calculation results with the model gave peaks power, dissipated during a cycle, not exceeding 6,5 W on discharge, 5 W on charge and 0,5 W on trickle.

Vibration tests

Six cells were tested to check wether if or not the definition was compliant with usual launching loading. Vibrations requirements indicated in table 4 were jointly accepted by ESA and CNES. Previous and later electrical characteristics were determined and no important effects observed.

Two cells were removed of the test and opened to perform a DPA but everything was found to be conform to the initial state. Finally these results demonstrate the hability of SAFT design to withstand reference loading level without showing any mechanical or electrochemical damages.

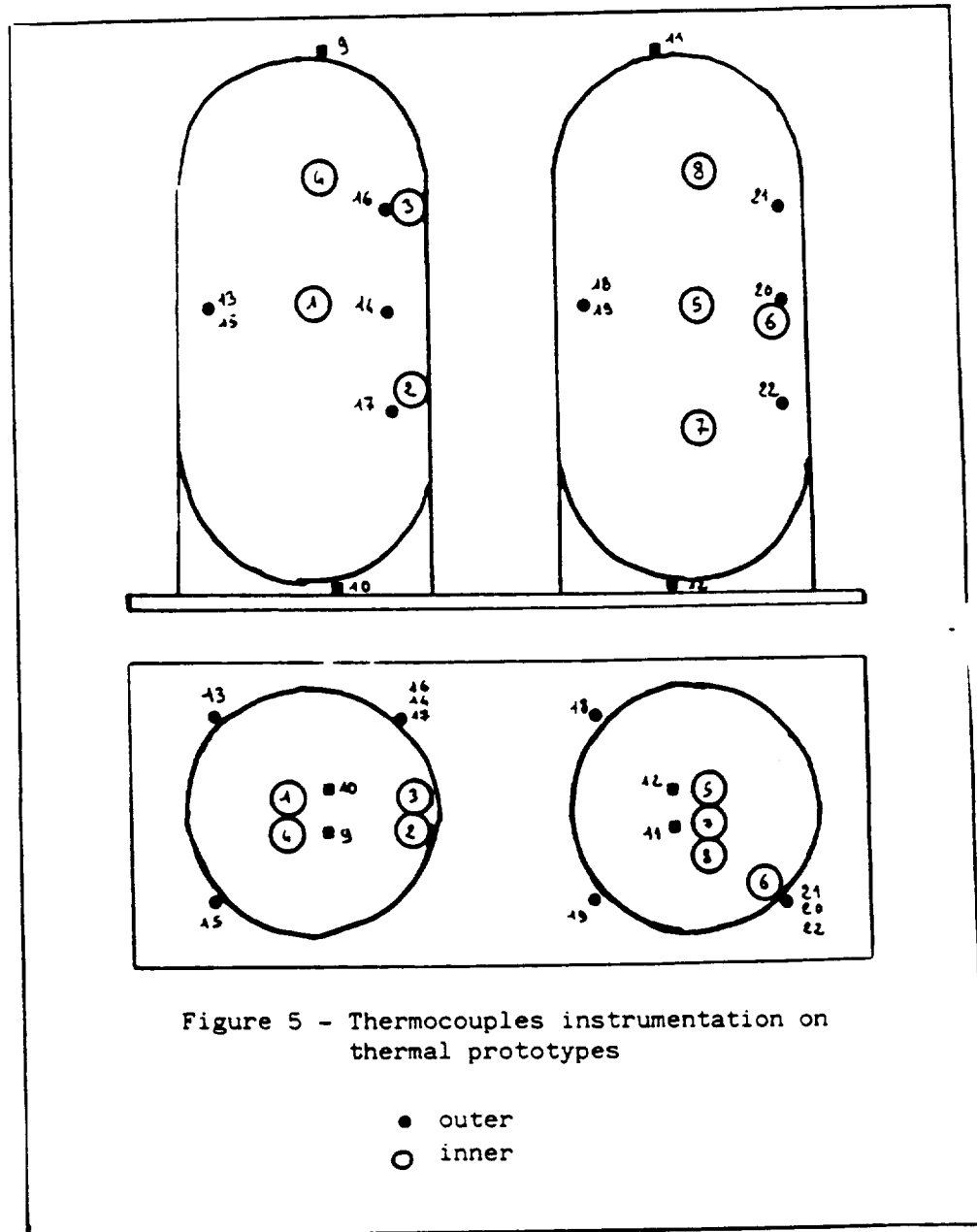
1) Sine vibrations			
10 -	22 Hz	: 22 mm C-C	
22 -	100 Hz	: + 20 g	2 octaves/minute
2) Random vibrations (along the 3 axis)			
20 -	150 Hz	: $0,25 \text{ g}^2/\text{Hz}$	
150 -	212 Hz	: + 12 db/oct	2 minutes per axis
212 -	480 Hz	: $1 \text{ g}^2/\text{Hz}$	23 g RMS
480 -	1000 Hz	: -12 db/oct	
1000 -	2000 Hz	: $0,053 \text{ g}^2/\text{Hz}$	

Table 4 - Vibrations spectra for qualification tests

Life tests

Three cells coming from the vibration test and six more unvibrated cells, or a total amount of nine, started a life test.

Cycling discharge profile is shown in figure 7 and related to a 45 cycles eclipse season, with a maximum discharge time of 72 minutes (this represent the typical case for Eutelsat 2 spacecraft application).



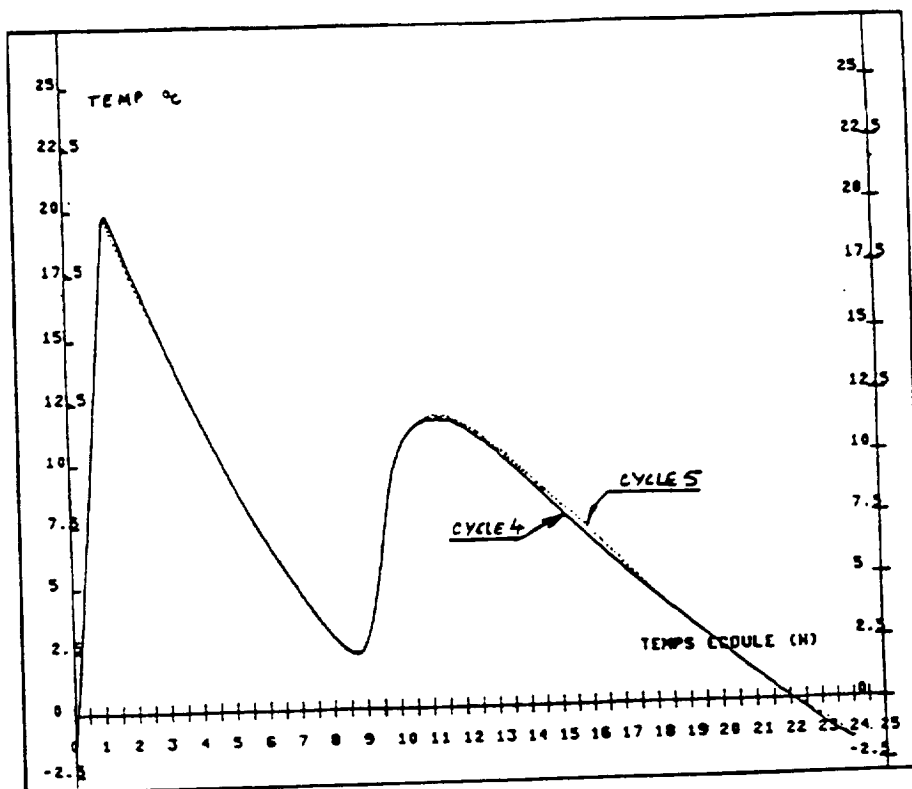


Figure 6 - Node's curve temperature

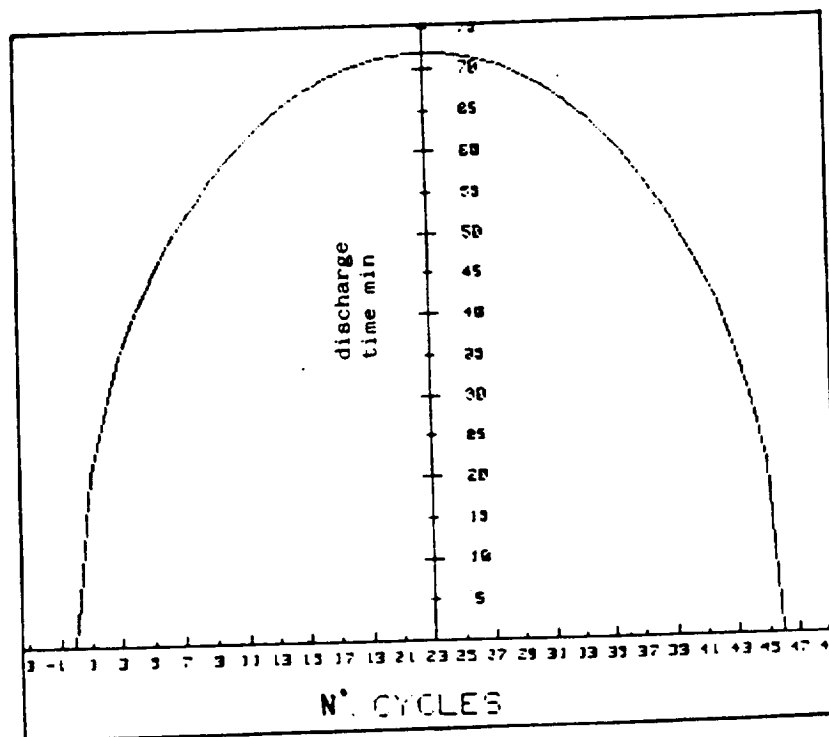


Figure 7 - Discharge time profile
used for life test

Cycling conditions are presented herebelow in table 5. The test remains very realistic because it is a low accelerated test (i.e. 2 cycles a day).

Discharge regim	C/1,7
Charge regim	C/13,5
Trickle regim	C/200
Maximum DOD	70 %
Recharge ratio K	1,15
Mean test temperature	10 + 5°C

Table 5 - Life test conditions

On figure 8 we establish the very low evolution on first three eclipse seasons on discharge step. Cells tested never exceeded 25°C outer temperature, and on maximum depth of discharge cycle, end of discharge voltage remained very stable at values close to 1,2 V.

This test is going on, one season more having been done, and normally it should only be stopped after completing 900 cycles or 20 eclipse seasons, corresponding to the ten years mission to be demonstrated.

Another encouraging result must be added. Apart of the validation test, a first prototype, cycling the same way, but at constant maximum DOD of 70 %, has reached satisfactorily more than 700 cycles.

Electrical evolution is shown in figure 9 and it is notably interesting to see how good is the stability for mid and end of discharge voltage. In addition, we should mentionned capacity evolution, checked regularly, hasn't decreased at all.

Considering thoroughly that kind of results, prequalification label was given to SAFT 50 Ah cell by CNES Quality Insurance Authority : which significate for the device the possibility to be mounted onto next term projects.

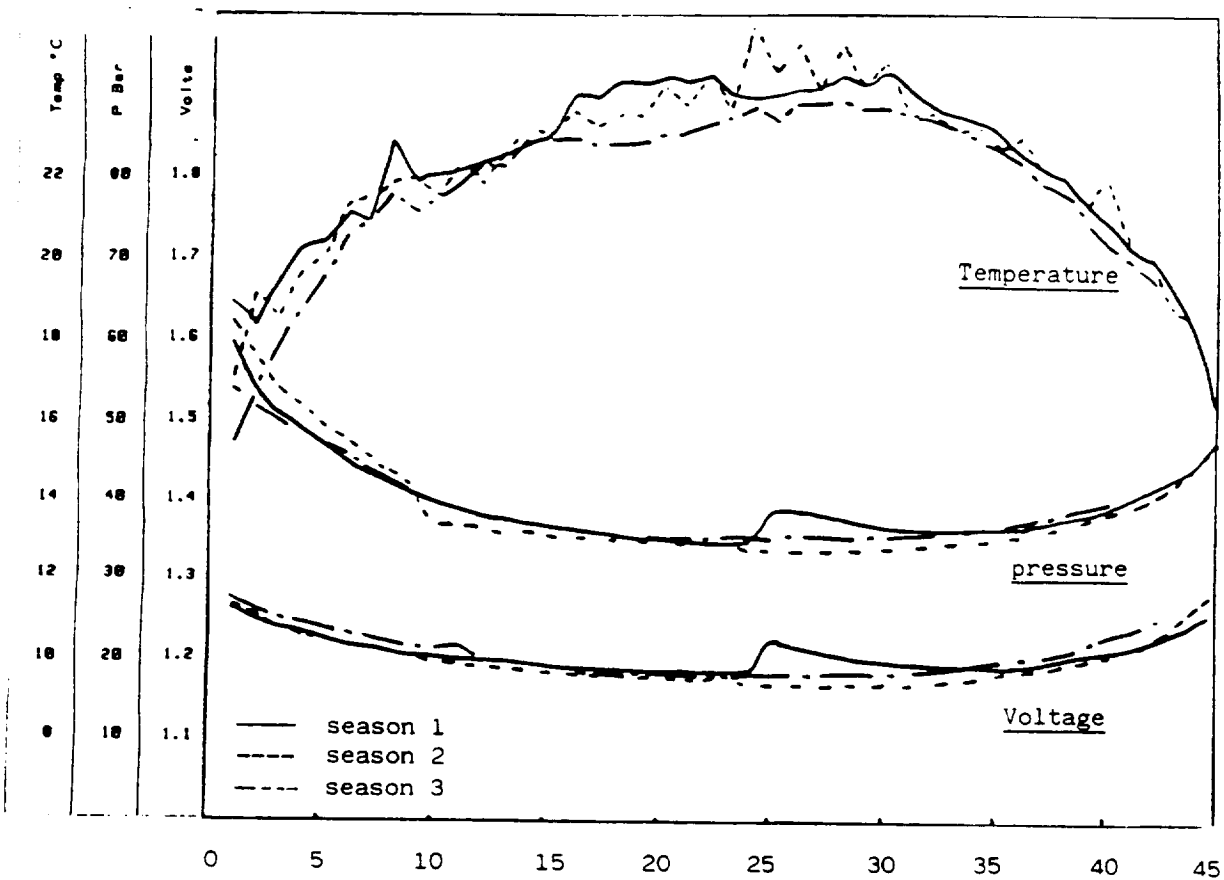


Figure 8 - Discharge characteristics evolution

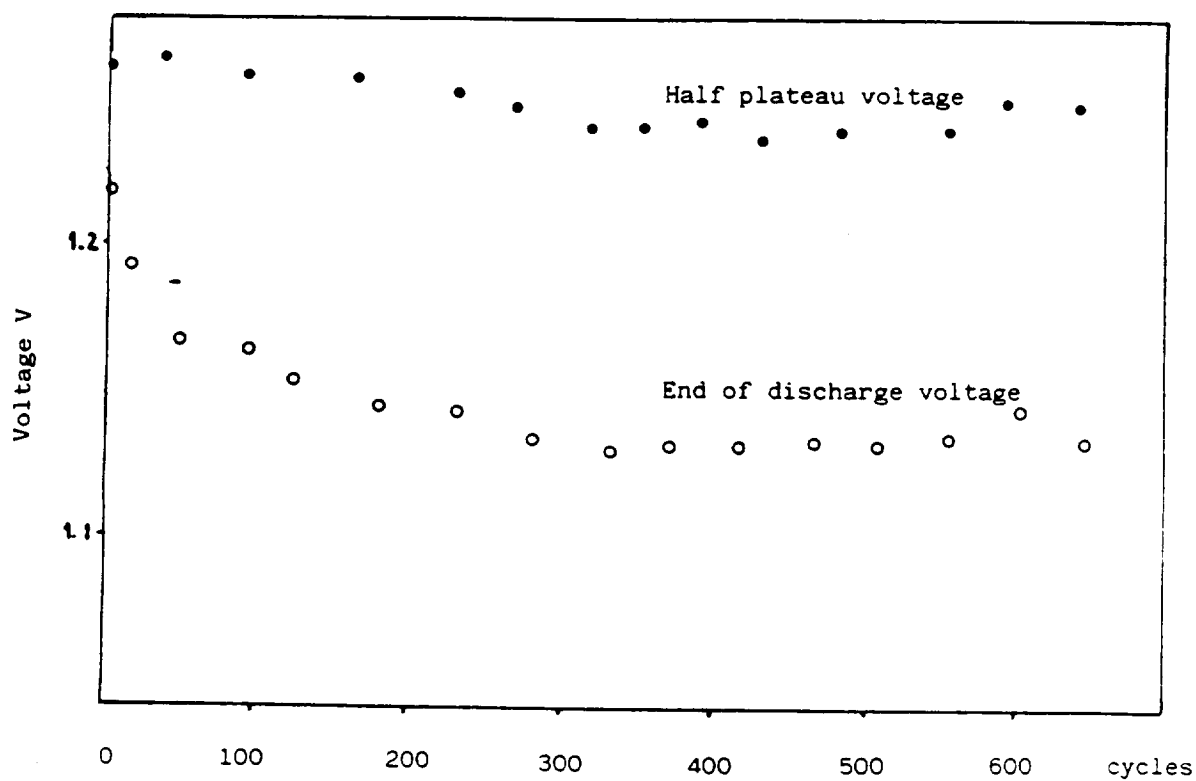


Figure 9 - Discharge voltage evolution with time

Future activities

ESA and CNES, with the high level of confidence got from the last development experience, decided jointly to initiate a new GEO development, while intending to improve performances at components level.

Main trends for the new GEO development can be summarized as follow :

- Wider range capacity : 40 - 90 Ah
- Longer life requirement : 12 years
- Light weight concept : 55 - 60 Wh/kg

Results will be available by the end of 1990.

At the same time, and because of interesting results (ref. 2) CNES and ESA have procured approximately 20 cells to be tested under LEO conditions.

CNES tests conditions will be typically 100 minutes cycle at 10°C and 40 % DOD with a goal of 30 000 cycles.

Next steps for french NiH_2 technology are driven by opportunities to be aboard, on SAT2 project (a technological GEO spacecraft belonging to ESA PSDE program) and on Columbus program (European contribution to the international space station).

CONCLUSIONS

Large effort has been made in France to promote a NiH_2 cell development to an advanced status. Important results deduced from a comprehensive program permit right now to ascertain our knowledge concerning this promising technology.

Specially, SAFT design was found to be correctly sized on vibration, thermal, mechanical, electrical and safety aspects, as proved by the prequalification status got.

Life time is still under evaluation with good chances to reach the objective of a ten years GEO mission.

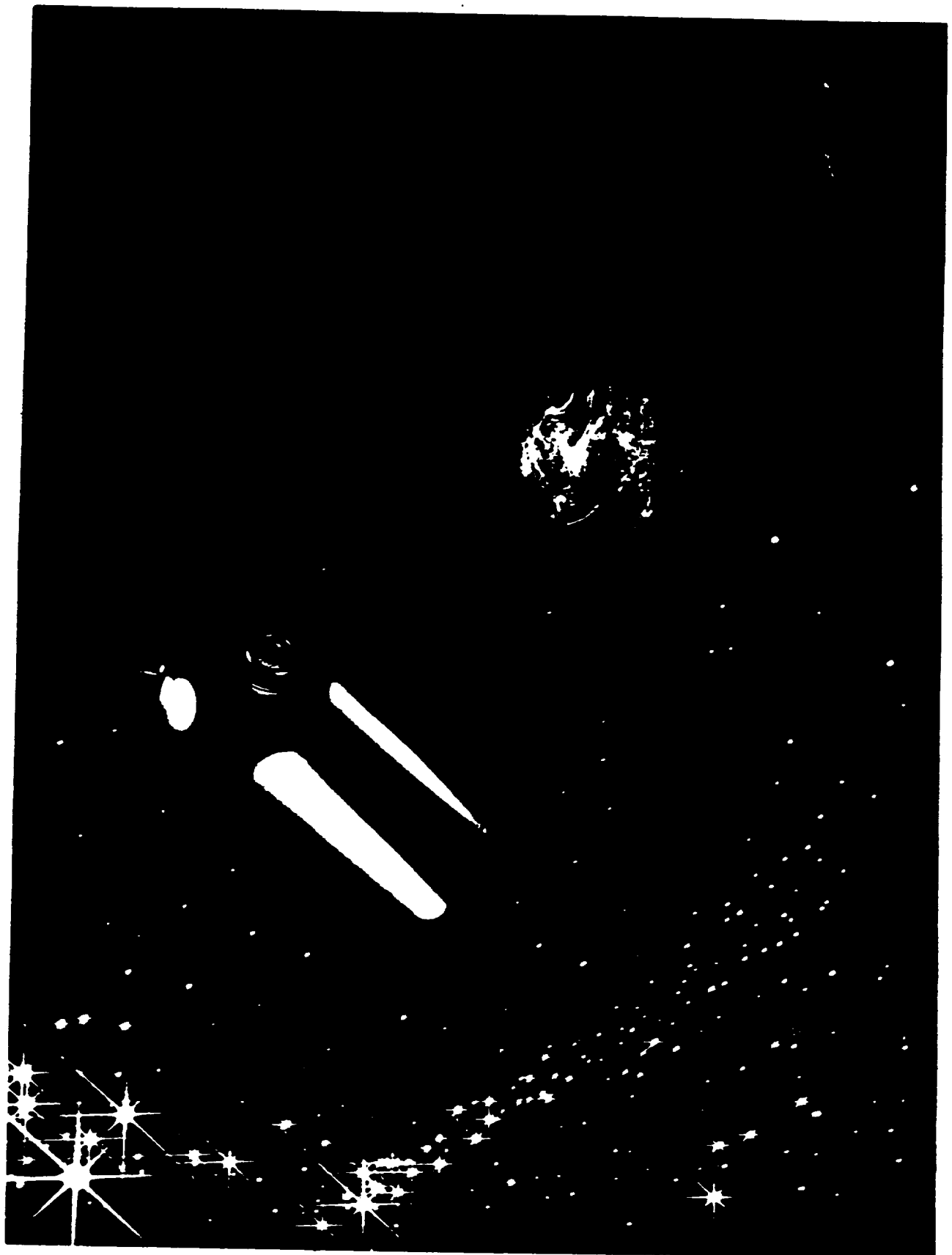
Ambitious improvements are planned for the next short term development with as key words, "high capacity and high energy density".

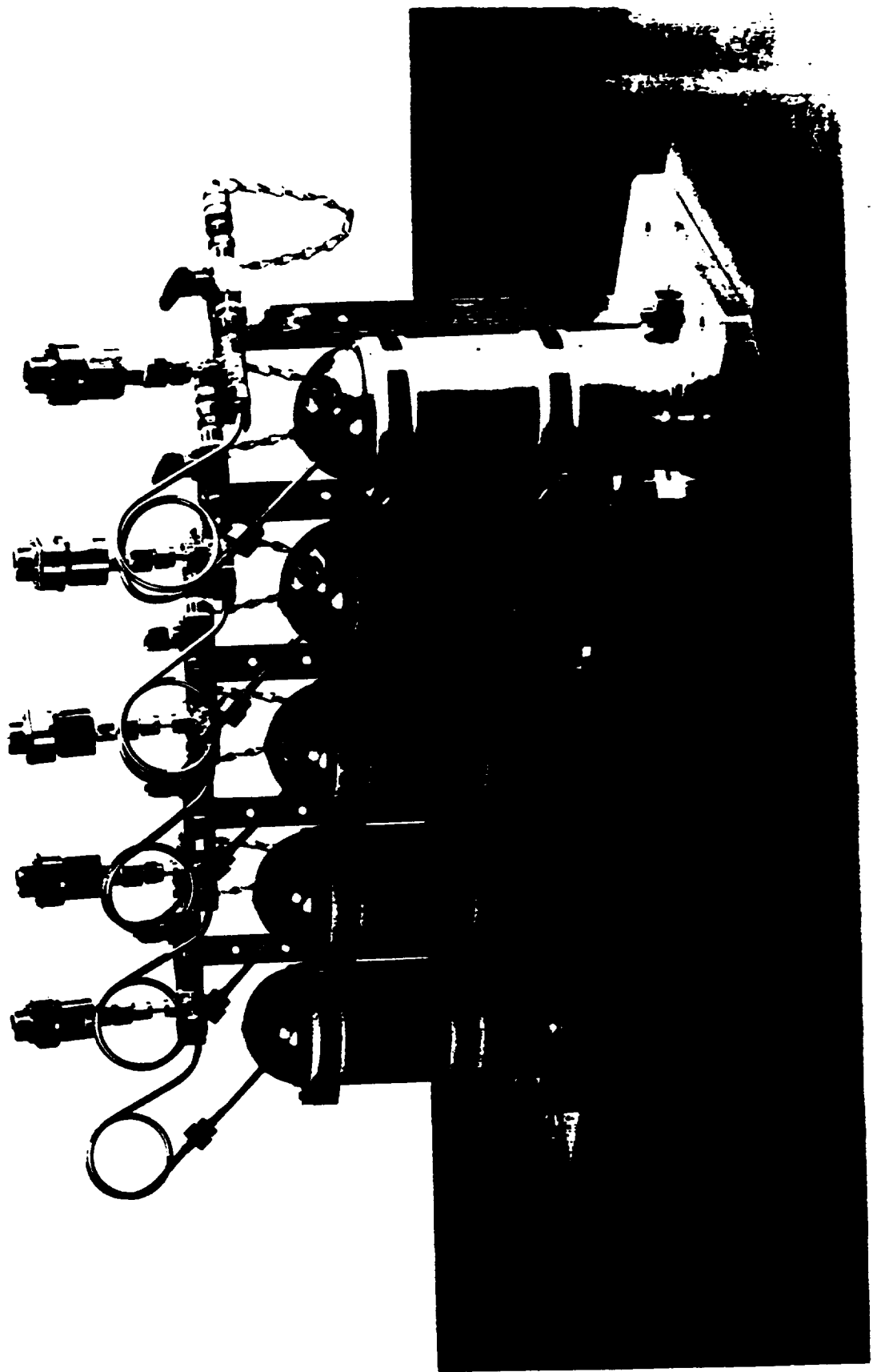
ACKNOWLEDGMENTS

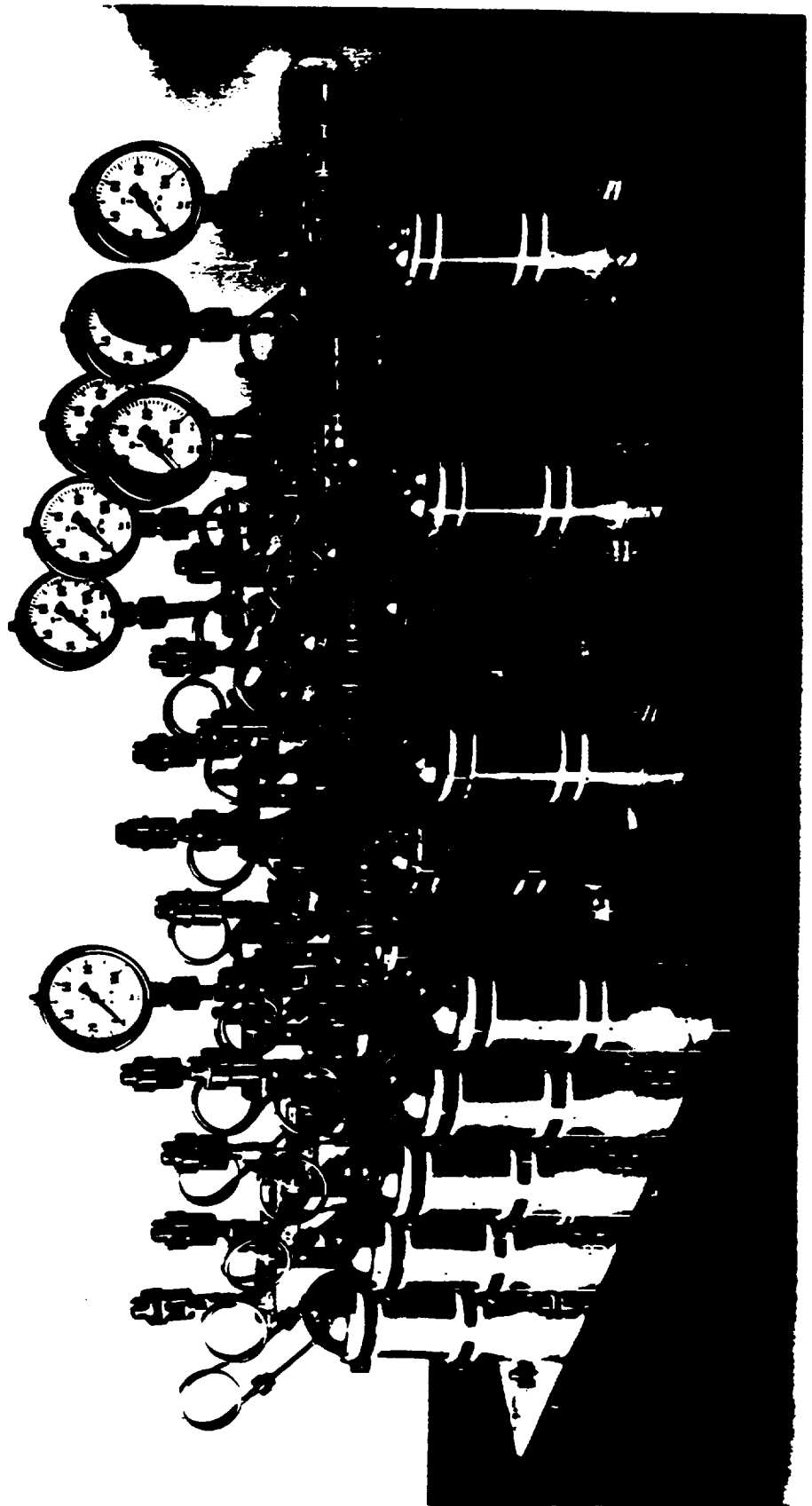
Our acknowledgments are particularly addressed to all people who have worked hard and therefore contributed to the success of this activity.

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2. G.J. DUDLEY - B. HENDEL WORMANN - Testing of European Nickel Hydrogen and silver Hydrogen cells for low earth applications - IECEC 1988 - Denver







SESSION IV

NICKEL-HYDROGEN TECHNOLOGY
SESSION II - Current Issues & Concerns

Chairman: J. Smithrick, NASA/LeRC

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November 1-3, 1988

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Storage Considerations for Ni-H₂ Battery Cells

1988 NASA/GSFC Battery Workshop, 3 Nov. 1988
Goddard Space Flight Center, Greenbelt, Maryland 20771

R.V. Whiteley, *Chemistry Department, Pacific University, Forest Grove, OR,*
and
A. Gibney, *O/62-12, Lockheed Missiles and Space Co., Sunnyvale, CA*

Introduction

The principal concern with the long term storage of nickel-hydrogen battery cells is the development of a low voltage plateau in the discharge profile of the cell (Figure 1). While the total capacity of a cell might remain essentially unchanged despite long periods of storage, the formation of this secondary plateau constitutes a decrease in the discharge voltage of some of the cells' capacity. When this lower voltage is below the voltage requirements of a particular power system, that portion of the capacity is no longer considered useful capacity, and therefore, there is a loss in useful capacity.

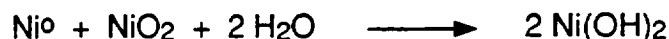
In order to understand this loss in useful capacity, the problem was characterized as fully as possible: the nature of the secondary plateau, the storage conditions which affect the development of the secondary plateau, the cell designs which make cells less likely to show losses in useful capacity after storage, and charging/ discharging regimes which lead to recovery of some useful capacity losses were all delineated (Table I). The strategy was, then, to formulate a mechanism for the capacity loss which would be consistent with all of these characteristics. Only with the correct mechanism in hand would it be possible to propose measures (storage, design, cycling) which would mitigate the loss of useful capacity after long term cell storage.

Discussion

The nature of this secondary plateau and its causes and effects (Tables 1 and 2) are consistent with the formation of a higher resistance barrier between the current -carrying sinter and the active material of the positive electrode. The nickel sinter intrinsically develops a thin barrier of NiO which inhibits electron transfer, and it is this barrier which protects the sinter from spontaneous oxidation by the Ni(III) and Ni(IV) hydroxides which are generated on cell charging. Without this barrier, the sinter would eventually become bivalent nickel hydroxide by way of:



and/ or



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The barriers of restive material can be thought of as of energy barriers as illustrated in Figure 2. Although the electrons in metallic nickel are at a considerably higher energy than those in the NiOOH and NiO_2 , there is minimal electron transfer, and therefore minimal oxidation of the sinter, because the electrons in the metallic nickel are unable to overcome the small energy barrier of the intrinsic oxide film. On the other hand, electrons in the platinum, negative electrode are at a sufficiently high energy to surmount this barrier when the platinum is exposed to H_2 gas; that is, when the cell contains any pressure of hydrogen.

It should be noted at this point that some of the other proposed mechanisms for the development of a secondary plateau after long term cell storage are not entirely consistent with the characteristics delineated in Table 1. For example, a recent explanation suggests that CoOOH (or Co(OH)_3) is reduced by the hydrogen gas in a Ni-H_2 cell and that this leads to differential solubilities of the nickel and cobalt hydroxides. It is proposed that there is a migration of Co from the active material matrix. Certainly, such a mechanism would profoundly affect the charge and discharge profile of a cell stored for long periods. But the secondary plateau is found in Ni-Cd cells despite the absence of hydrogen, and it is found in Ni-H_2 cells with a positive precharge. Such cells have a residual oxidizing environment, and reduction of Co(III) in the active material would be highly unlikely. Even Ni-H_2 cells with a modest hydrogen precharge show residual Ni(III) in their positive electrodes after several years of storage in the shorted condition. In the presence of Ni(III) , the reduction of Co(III) to bivalent Co is unlikely.

The NiO film on the nickel sinter is not the only energy barrier between the metallic nickel and the active material: the active material itself can provide considerable electrical resistance (a high energy barrier). The height of this barrier is indeterminate because the electrical resistance of the active material barrier is largely a function of its thickness, its structure, and the oxidation state of the Ni within its structure. The fully discharged positive electrode contains mostly bivalent nickel hydroxide. There is the brucite form, usually referred to as $\beta\text{-Ni(OH)}_2$, and there is the loosely hydrated form, $\alpha\text{-Ni(OH)}_2$ which can contain 0.5 to 0.7 molecules of H_2O per Ni atom. This alpha form is a much more open structure as its intercalated water molecules hold the Ni-O planes 0.8 nm apart. This is also a much more electrically conductive material than the $\beta\text{-Ni(OH)}_2$ which contains as little as one H_2O molecule per twenty Ni atoms and has an interlaminar spacing of only 0.46 nm.

So, although a higher energy barrier might be expected of the $\beta\text{-Ni(OH)}_2$ than of the $\alpha\text{-Ni(OH)}_2$ active material, other considerations determine the exact barrier heights. It is evident that the $\beta\text{-Ni(OH)}_2$ barrier can become insurmountable to even those electrons from the charged negative electrode. This conclusion is drawn from the destructive physical analyses of cells which have been short-circuited for years: the apparent oxidation state of the nickel in the active material is always found to exceed +2, indicating the presence of at least some trivalent nickel. The analyses typically show

about 5% NiOOH in the active material and it has been observed that the discharged active material is β -Ni(OH)₂. For the most part, however, the active material is accessible for discharge, and this is largely at about the same energy or voltage. Highly resistive regions do not compromise all of the capacity because the positive electrodes behave much like a network of innumerable parallel resistors (Figure 3). The high resistance paths are simply bypassed until all of the active material in low resistance regions is discharged. Only then is the more isolated material discharged.

The highly resistive nature of the β -Ni(OH)₂ is due, only in part, to the lack of water in its interlaminar regions. As this bivalent hydroxide ripens, its structure becomes more and more regular (ordered), and it is the highly ordered form of β -Ni(OH)₂ which shows such poor electrical conductivity. Water is not the only defect in the structure which can enhance the electrical conductivity of the material: even traces of higher oxidation state material like NiOOH can have a profound effect. And so, while it might seem desirable to achieve total reduction of the higher oxidation state nickel when discharging a cell, it is preferable to leave traces of the Ni(III) and Ni(IV) within the active material matrix to act as defects as the β -Ni(OH)₂ ripens over time. Fortunately, leaving some undischarged material is unavoidable as discussed earlier.

Charged positive electrodes have been found to contain α -NiOOH, β -NiOOH, γ -NiOOH, and some form of tetravalent Ni which, for simplicity, will be described here as NiO₂. The β -NiOOH and γ -NiOOH are the important charging products. It is generally accepted that the beta structure is more conductive than the gamma structure, but the key issue is the structures themselves. On charging of the cell β -Ni(OH)₂ is smoothly oxidized to β -NiOOH with only minor changes in the crystal structure. The interlaminar distance opens slightly, from 0.46nm to 0.48nm. γ -NiOOH on the other hand is a product of charging α -Ni(OH)₂ or of prolonged overcharging of β -NiOOH, and this, as with the α -Ni(OH)₂, is a much more open structure. Cell dimensions indicating an interlaminar spacing of 2.1nm have been reported. The separation of the Ni-O planes in this structure is attributed to the incorporation of K⁺ ions which are drawn into the structure during charging and expelled during discharging.

Because the γ -NiOOH is a poorer conductor than the β -NiOOH, the γ -NiOOH material discharges at a lower voltage and is therefore a less desirable product of cell charging. However, it is the precursor to α -Ni(OH)₂, and in that respect it is more desirable to form γ -NiOOH on cell charging. By forming γ -NiOOH through extended overcharging, α -Ni(OH)₂ will be formed on subsequent discharge, and this more conductive form of discharged material will provide a lower energy barrier between the active material and the nickel sinter. This is why some capacity lost to the low voltage discharge can be recovered through severe overcharging of the cell: any active material which has not been isolated by highly resistive β -Ni(OH)₂ is charged, first to β -

NiOOH and then on to γ -NiOOH. This opens the structure of the active material allowing H₂O and K⁺ between the layers of Ni and O atoms. On discharge, a significant amount of α -Ni(OH)₂ is formed in the pores of the sinter. Repeated cycling (over-charging and discharging) slowly works H₂O into the structure of the active material. This is not likely to be an efficient process, and so, total recovery of capacity is not expected. When the β -Ni(OH)₂ becomes highly ordered (dehydrated) after prolonged storage, it is not easily re-hydrated and therefore it remains highly resistive.

The hypothesis that the loss of useful capacity is a dehydration process is consistent with most of the factors delineated in Table 1. Dehydration of either form of Ni(OH)₂ is thermodynamically favorable, and so, the discharged, active material has a natural tendency to lose water and become less conductive. But dehydration is a slow process and can be virtually eliminated at very low temperatures (*cf.* Table 2). Dehydration could readily occur in cells with no H₂ precharge as is the case in Ni-Cd and negative-limited Ni-H₂ cells, and some low voltage discharge plateau has been observed in both of these cell designs (Table 2). Recovery of capacity by overcharge and trickle charge is not surprising when these reactions at the positive electrode are examined (Table 3). The trickle charge reaction is the same as the overcharge reaction: both consume hydroxide ions, but more important, both generate H₂O within the active material and this is the source for the "re-hydration" process. The final factor described in Table 1 is not obviously connected to dehydration of active material.

The sensitivity of capacity loss to the rigidity of the plaque is due to the significant changes in the volume of active material as a function of state-of-charge. Zimmerman and Effa have clearly demonstrated that the intrinsic volume of discharged material (β -Ni(OH)₂) is considerably larger in a fully discharged cell than in a partly charged cell (Figure 4). This implies that when a cell is fully discharged, the active material swells inside the pores of the nickel sinter creating stresses within the positive electrode. These stress can be relieved by expansion of the pores or by squeezing water from the Ni(OH)₂ structure to reduce its volume. Expansion of the pores is a function of the rigidity of the plaque, and for plaque with a high bend strength, this is less likely. This leaves only the dehydration option. Given that dehydration of Ni(II) hydroxides is already thermodynamically favorable, the stresses created by rigid plaque can only accelerate the process. And given that the highly conductive α -Ni(OH)₂ occupies much more volume than the less conductive β -Ni(OH)₂, more rigid plaque should favor formation of β -Ni(OH)₂.

Closely related to the issue of rigid plaque is loading levels: electrodes which are heavily loaded, like rigid plaque, are less able to expand to accommodate α -Ni(OH)₂ as the cell is discharged. And so, such electrodes are more likely to enhance the formation of the highly resistive, dehydrated β -Ni(OH)₂ which leads to the secondary voltage plateau. It has been pointed out that plaque contains large void volumes even after being heavily loaded, but it should also be pointed out that access to these

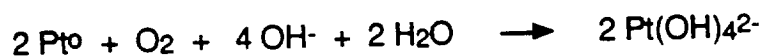
voids is the issue. It is unlikely that any form of nickel hydroxide has any ductility to speak of, and therefore, as it expands, it is unlikely that it would flow into any available voids. Instead, it will create stresses within the electrode pores and spontaneously dehydrate.

The hypothesis that the loss of useful capacity is a dehydration process is not consistent with all of the factors delineated in Table 1. These inconsistencies are explained when a more general description of the process is used. It is the highly ordered form of $\beta\text{-Ni}(\text{OH})_2$ which is a poor conductor, and the presence of crystal defects, like H_2O , enhance its conductivity. Other defects, however, are possible and are vital to maintaining good conductivity within the active material. Either form of NiOOH serves this purpose well. Besides providing Ni^{3+} defects within the $\beta\text{-Ni}(\text{OH})_2$ structure, neither form of NiOOH has as much tendency to dehydrate as the two forms of $\text{Ni}(\text{OH})_2$ and the $\gamma\text{-NiOOH}$ brings with it K^+ ions which further disrupt the highly regular structure of the $\beta\text{-Ni}(\text{OH})_2$. The need for NiOOH within the discharged active material explains the observations that cells with a hydrogen precharge and cells stored in the shorted condition are more likely to develop a secondary plateau (Tables 1 and 2).

The NiOOH defects can be removed from the active material matrix by any or all of the reactions listed in Table 3 for self discharge at the nickel electrode. The first reaction listed does not require hydrogen; it is the mechanism for self discharge of Ni-Cd cells. If it occurs in a Ni-H_2 cell, it is evidently coupled to the self discharge reaction under "At the Platinum Electrode or on Any Ni^0 Surface" (Table 3), because O_2 does not accumulate during Ni-H_2 cell self discharge. Nevertheless, in a discharged cell, the higher oxidation state nickel ions are spontaneously removed from the matrix by the electrolyte and by any hydrogen precharge, the greater the H_2 precharge, the more thoroughly the NiOOH can be removed from the matrix. Inasmuch as residual NiOOH is always found in Ni-H_2 cells, even those stored for long periods with a hydrogen precharge, it can be said that this reduction process is not absolutely complete.

The intrinsic nature of each electrode in a fully discharged cell is very much a function of the precharge on the cell (Tables 4A and 4B). With either cell design, the open circuit voltage of the positive electrode should lie at least 100 mV positive of the negative electrode (Table 5). This means that in either design the positive electrode is inherently electron-deficient with respect to the negative electrode. When, however, the electrodes are shorted together after full discharge, the potential of each electrode is driven to exactly the same value and this causes the positive electrode to become artificially electron-rich (and the negative, artificially electron-poor). This electron-rich environment will enhance the reduction NiOOH defects in the active material. This is why cells stored shorted consistently show a greater proclivity for the secondary plateau (Table 2). On the other hand, when a cell is stored at open circuit after discharge, each electrode remains at its intrinsic rest potential and an artificially electron-rich (reducing) environment is not created within the positive electrode.

Purely in terms of mitigating the secondary voltage plateau, it is apparent that the negative limited cell (that with a positive precharge) is preferable. With its positive precharge, a higher concentration of NiOOH defects remain in the active material matrix after fully discharging the cell. But other storage issues should be considered. Because NiOOH can be reduced by H₂O to produce O₂, as described earlier, it should not be expected that a negative limited cell will retain its precharge as NiOOH. Rather, on prolonged storage, the positive precharge is probably inventoried as O₂ gas. The disadvantage of this is that the precharge is then no longer confined to the positive electrode; it is free to move throughout the cell. As the cell is recharged, H₂ will be generated at the negative electrode, and the H₂ + O₂ recombination to form H₂O will quickly follow. But prior to recharge, the liberated oxygen gas can be problematic. In an alkaline solution, as in the Ni-H₂ cell, oxygen can readily dissolve platinum metal from the negative electrode by:



Other platinum oxidation processes can be written, and all of them show that the platinum becomes a soluble material which can diffuse throughout the cell. Only the oxidized platinum which remains in contact with the negative electrode would be reduced back to Pt metal on charging the cell. When the negative limited cell is stored shorted, the oxidation of Pt from the negative can proceed without the need for the O₂ shuttle. In this case the electron deficiency created at the negative is enough to drive the oxidation reaction.

Conclusions

The loss of some capacity after prolonged storage of Ni-H₂ batteries and battery cells is unavoidable; it is simply a consequence of confining several elements, each existing in two or more oxidation states, to a single container for extended periods. Thermodynamically, the oxidation-reduction reactions are highly spontaneous as are the deleterious dehydration reactions which cause the active material to lose its conductivity. But the rates of these reactions, particularly below room temperature become sufficiently slow to make capacity losses acceptably small. Other measures, besides low temperature storage can further decrease the rate of capacity-draining reactions. The discharge prior to cell storage should be somewhat modest, *i.e.* it should not be so thorough as to drive both electrodes to the same voltage (a zero volt open circuit condition). The use of minimal hydrogen precharge, and open circuit storage of the cells also slow the reduction of NiOOH in the active material. With such relatively simple precautions, it should be possible to store Ni-H₂ batteries and battery cells for prolonged periods with virtually no capacity loss to a low voltage plateau.

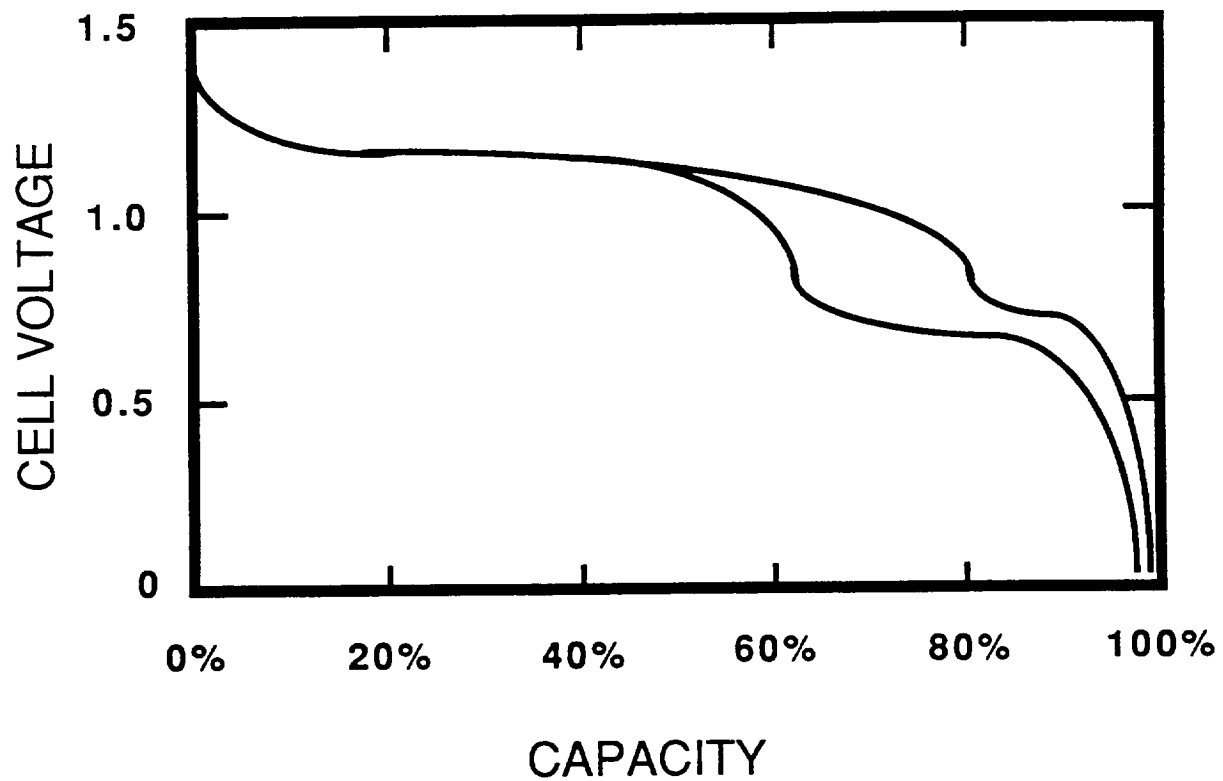


Figure 1 Two discharge profiles: one with a small secondary plateau and another with a significant secondary plateau.

ENERGY LEVEL DIAGRAM for Ni/H₂ CELL

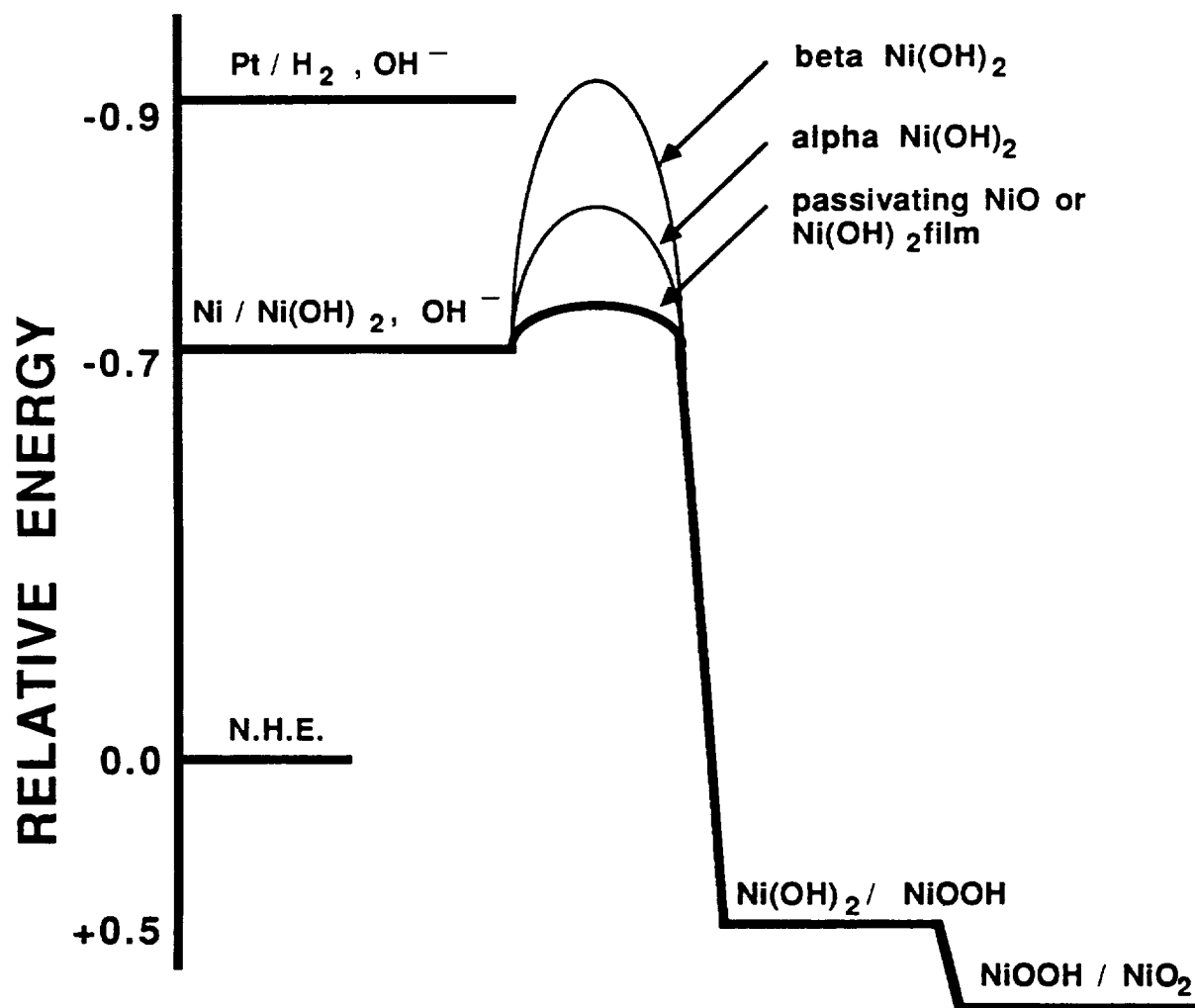


Figure 2. Relative energies of electrons in the various materials in the Nickel-Hydrogen cell electrodes. For a single electron the ordinate is expressed in electron volts; for one Coulomb, this axis would be in expressed Joules.

PARALLEL RESISTOR MODEL

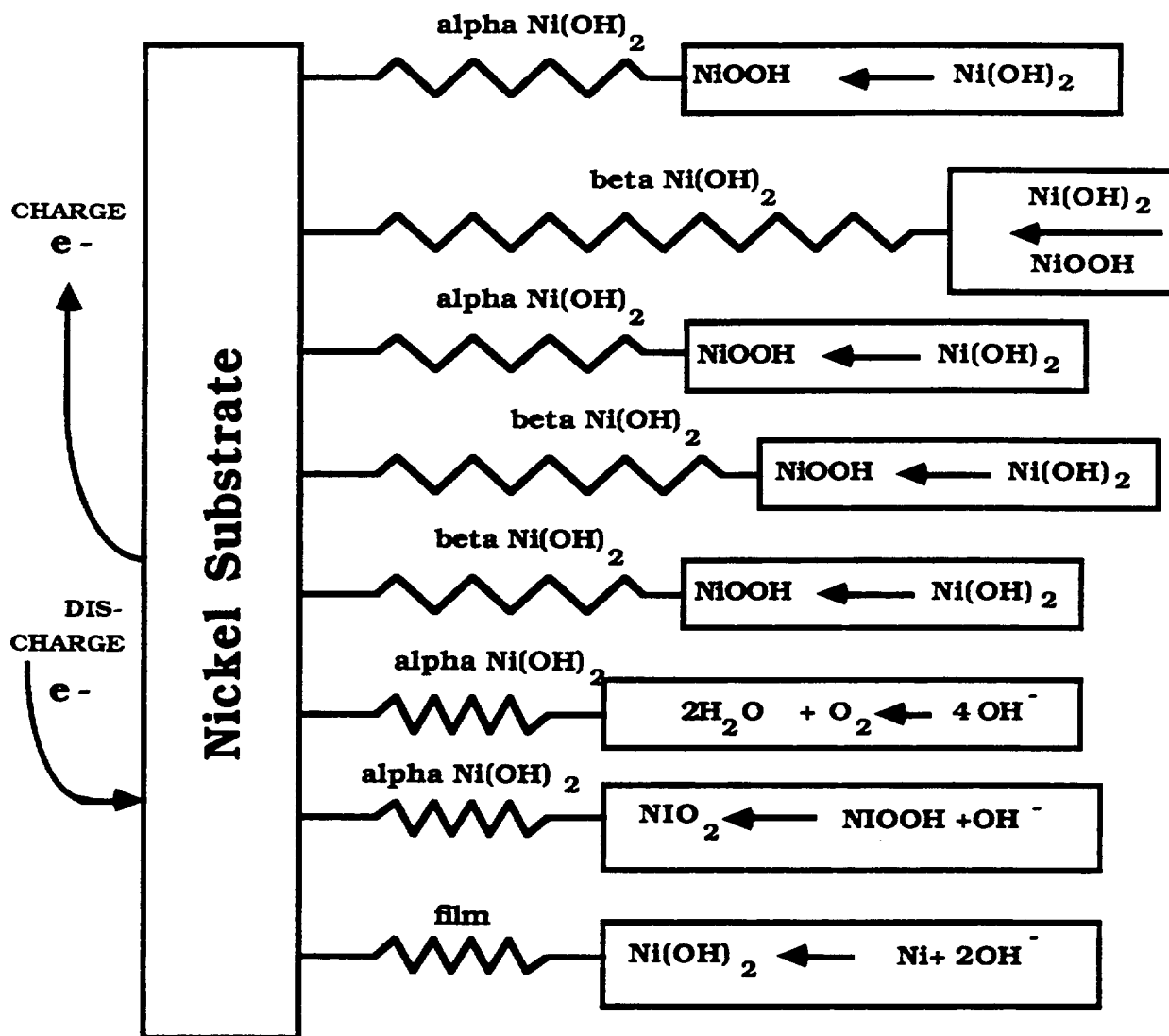


Figure 3. A parallel resistor model illustrating the many different resistive barriers between the nickel sinter and the active material. The boxes represent regions of active material, and the arrows within those boxes are in the direction of the charging reaction. The length of a particular resistor is an indication of its relative resistance.

From: A.H. Zimmerman and P.K. Effa, Nickel Hydroxide Active Material Densities, Aerospace Technical Memorandum SD-TR-88-02, Aerospace Corporation, El Segundo, CA 90245-4691.

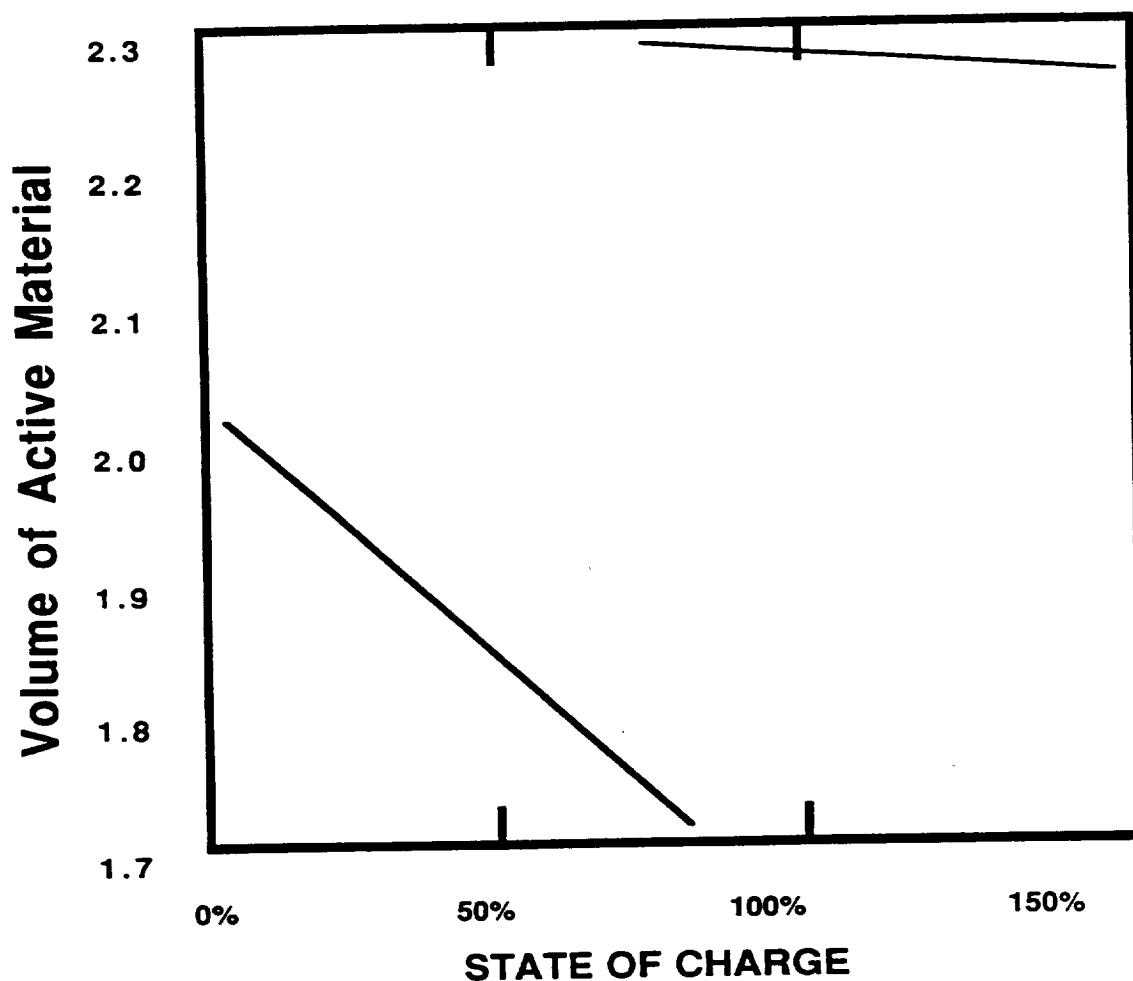


Figure 4 The volume of active material as a function of state of charge for a nickel electrode containing 10% cobalt hydroxide in the active material.

Table 1

CHARACTERISTICS of the SECONDARY VOLTAGE PLATEAU PROBLEM

It diminishes useful capacity (up to 30% loss).

The total capacity is essentially retained, but a significant portion is shifted to a discharge voltage of less than 0.9 V

It develops relatively slowly, even at room temperature.

The rate of development is clearly affected by temperature.
It is almost non-existent at 0°C and below.

The severity of the problem depends upon cell precharge.
It is sensitive to the presence of H₂ pressure.

The plateau is more prominent in cells stored shorted.

It diminishes charge efficiency.
Cells with this plateau show premature oxygen evolution.

Capacity loss can be recovered with severe overcharging.

The problem is somewhat mitigated with trickle charge.

It seems to be sensitive to physical properties (rigidity) of the plaque.

Table 2

REFERENCE DATA

From: H. Vaidyanathan, Long-Term Storage of Nickel-Hydrogen Cells, COMSAT Laboratories, Clarksburg, MD 20871-9475

Five cells were fully discharged and stored open-circuit at room temperature. After 30 days, all five cells had retained at least 71% of initial capacity.

Fully discharged cells stored open circuit at 0°C retained more than 90% of initial capacity after 253 days in storage, and cells stored at -20°C showed 103% of initial capacity after similar storage period.

With -20°C, 0°C, and room temperature storage of fully discharged, open circuited cells, those with a negative precharge (residual H₂ pressure after discharge) always lost the greater fraction of initial capacity.

From: B. Vyas and M.P. Bernhardt, Effects of the Mode of Storage on the Capacity Fading of the Sintered Nickel Electrode, 1981 Goddard Battery Workshop.

Loss in Capacity for Ni-Cd Cells

<u>STORAGE CONDITION</u>	<u>STORAGE TEMPERATURE</u>		
	<u>Room Temp.</u>	<u>60°C</u>	<u>80°C</u>
Shorted	5	30	37
Open Circuit	2	6	17

Table 3

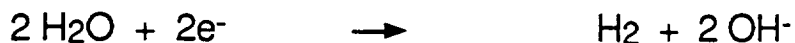
Reactions of Interest

Charge

At the Nickel Electrode



At the Platinum Electrode



Overcharge

At the Nickel Electrode

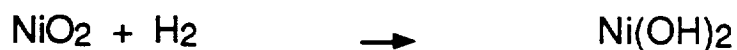
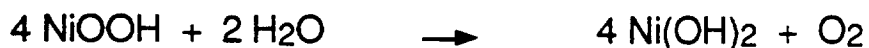


At the Platinum Electrode



Self Discharge

At the Nickel Electrode



At the Platinum Electrode or on Any Ni⁰ Surface



Table 4B

THE NEGATIVE LIMITED CELL

- Will contain no residual hydrogen, not even adsorbed to the negative electrode.
- Will contain electrochemically available NiOOH in the positive electrodes.
- All remaining NiOOH will continue to be reduced, but by H₂O only.
- Oxygen gas could accumulate in the discharged cell.

Shorted for Storage

- Both electrodes will be driven to the same potential.
- The positive electrode will enhance oxidation at the negative electrode, and with no adsorbed H₂ to be oxidized:



- The negative electrode will drive electrons into the positive electrode thereby accelerating the reduction of electrochemically available NiOOH.

Open Circuit for Storage

- Each electrode is allowed to achieve its rest potential.
- Neither electrode drives the other.

Table 4A

THE POSITIVE LIMITED CELL

- Will contain a residual pressure of hydrogen gas after full discharge. The negative electrode will, therefore, contain adsorbed hydrogen.
- Will contain no electrochemically available NiOOH in the active material (positive electrode) after full discharge.
- Non-electrochemically available NiOOH will continue to be reduced, either by H₂O or by H₂. The extent and rate of this reduction will depend largely on the amount of H₂ precharge.

Shorted for Storage

- Both electrodes will be driven to the same potential.
- This will enhance oxidation of the adsorbed layer of H₂ at the Pt (negative) electrode.
- Reduction of Ni(OH)₂ and Co(OH)₂ in the positive electrode will be enhanced.
- The artificially induced reducing environment in the nickel (positive) electrode will drive the reduction of NiOOH.

Open Circuit for Storage

- Each electrode is allowed to achieve its rest potential.
- Neither electrode drives the other.

Table 5

ESTIMATES of ELECTRODE REST POTENTIALS For Two Cell Designs

The positive limited cell:

The negative electrode is Pt/ H₂, OH⁻ E = -0.85 V vs N.H.E.

The positive electrode is Ni/ Ni(OH)₂, OH⁻ E = -0.73 V vs N.H.E.

The negative limited cell:

The negative electrode is Pt/ Pt(OH)₂, OH⁻ E = +0.15 V vs N.H.E.

The positive electrode is Ni/ Ni(OH)₂, NiOOH E = +0.47 V vs N.H.E.

Table 6

SUMMARY

.The active material in a fully discharged cell is a mixture of α -Ni(OH)₂, β -Ni(OH)₂, and higher oxidation state hydroxides of Ni, principally β -NiOOH.

-This material is an excellent electrical conductor and therefore is easily charged.

-The excellent conductivity is due to:

.The presence of α -Ni(OH)₂ because of its open lattice which holds H₂O molecules between Ni-O planes.

.The presence of Ni(III) and Ni(IV) hydroxides and oxides. These create defects in the β -Ni(OH)₂ lattice as it forms. Also, these hydroxides do not readily dehydrate.

-Over extended storage:

.The bivalent hydroxides dehydrate, and the oxyhydroxides are reduced.

.A highly ordered form of beta-Ni(OH)₂ slowly forms. This material is a poor electrical conductor.

-Dehydration is thermodynamically favorable and is accelerated by:

.Elevated temperature

.Compression of the active material by rigid plaque.

-Reduction of the oxyhydroxides is also thermodynamically favorable and is accelerated by:

.High pressure hydrogen (hydrogen precharge)

.Shorting the positive electrode to the negative electrode during storage

Table 7

RECOMMENDATIONS

- Use minimal negative precharge after cell activation.**
- Store cells at low temperature (*ca.* 0°C).**
- Store cells in open circuit condition after full discharge.**

Table 8

ADDITIONAL REFERENCES

- P.C. Milner and U.B. Thomas, *Advances in Electrochemistry and Electrochemical Engineering*, Interscience Publishers (1967), New York, C.W. Tobias (ed.), **5**, 1-86.
- R.S. McEwen, "Crystallographic Studies on Nickel Hydroxide and the Higher Nickel Oxides," *J. Phys. Chem.*, 1782-1789, **75**, (1971).
- R. Barnard, G.T. Crickmore, J.A. Lee, and F.L. Tye, "The Causes of Residual Capacity in Nickel Oxyhydroxide Electrodes," *J. Appl. Electrochem.*, **10**, 61-70, (1980).
- D.H. Fritts, "The Mechanics of Electrochemically Coprecipitated Cobalt Hydroxide in Nickel Hydroxide Electrodes," *J. Electrochem. Soc.*, **129**, 118-122, (1982).
- B. Mani and J.P. de Neufville, "Dehydration of Chemically and Electrochemically Impregnated (CI and EI) Nickel Hydroxide Electrodes," *J. Electrochem. Soc.*, **135**, 800-803, (1988).

Electrolyte Concentration Effects on Ni-H₂ Battery Cells

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Lockheed Missiles and Space Co.

R. Whiteley

Pacific University

R. Baker

Eagle-Picher Industries

CELL SUMMARY

Application:

Hubble Space Telescope

Nameplate:

93 Ahr

Normal DOD:

8 - 10%

Cell Design Features:

- **Eagle-Picher Manufactured**
- **Back-to-back, Air Force Electrodes**
- **Zircar Separators**
- **Rabbit Ear Terminals with Ziegler Seals**

Engineering Cell Electrolyte:

- **Cell populations activated with either 25 w/o (eg cell 12) or 31 w/o (eg cell 31) KOH**
- **Additional cells (eg cell 5) subjected to special activation procedure with 31 w/o KOH**
- **Actual post-conditioning electrolyte concentration shown by DPA**

DPA Results of Engineering Cells

Table 1 DPA DATA 25% vs 31% KOH (STARTING CONCENTRATION)

PROPERTY	25% KOH (Cell #12)	31% KOH (Cell #13)	Double Activation (Cell #5)
Electrolyte Takeup, g	282.0 (avg. of 5 cells)	304.4 (avg. of 5 cells)	288.7 (avg. of 3 cells)
Plate Thickness (mils)			
Avg. from DPA	37.0	39.7	44.9
Avg., Pre-activation	35.5 1.5	36.0 3.7	43.3 35.1 8.2
Electrolyte Conc. %			
In positive electrodes	30.7	38.8	38.9
In negative electrodes	34.3	37.8	35.9
In separators	26.7	34.8	39.7
Weighted average		28.6	36.7
Bulk Porosity, %	85.02	85.50	86.67
Active material in positive electrodes, %	48.43	48.02	47.79

Figure 1 *Electrolyte wt. in DPA cell components*
(corrected for carbonate)

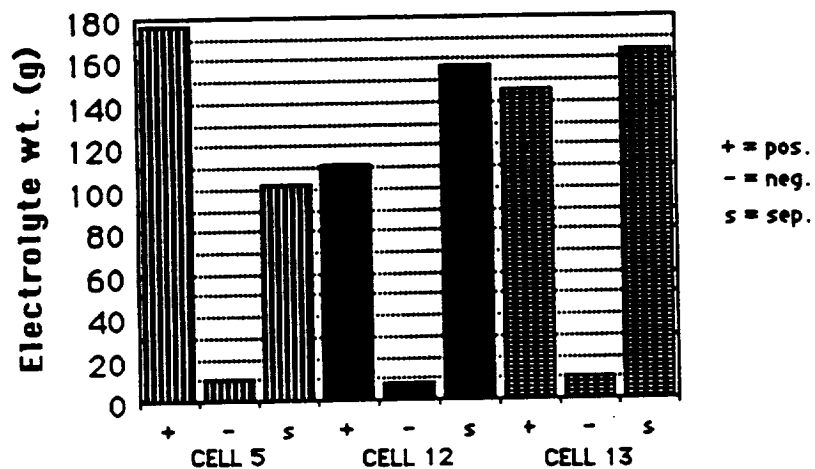


Figure 2 *Electrolyte conc. in DPA cell components*
(corrected for carbonate)

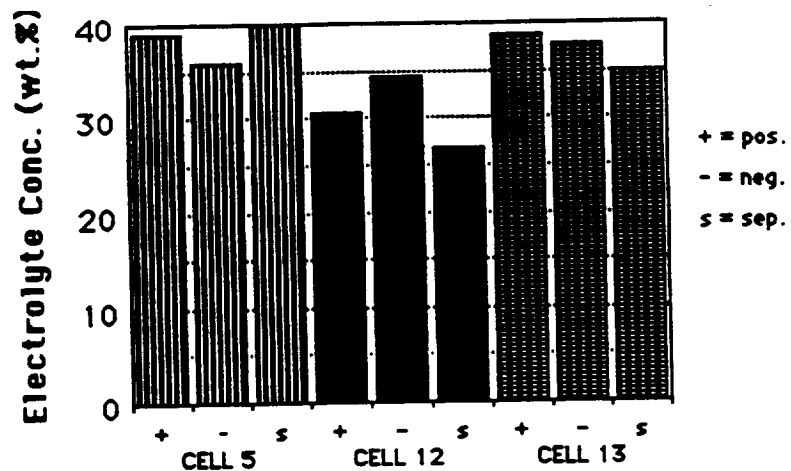
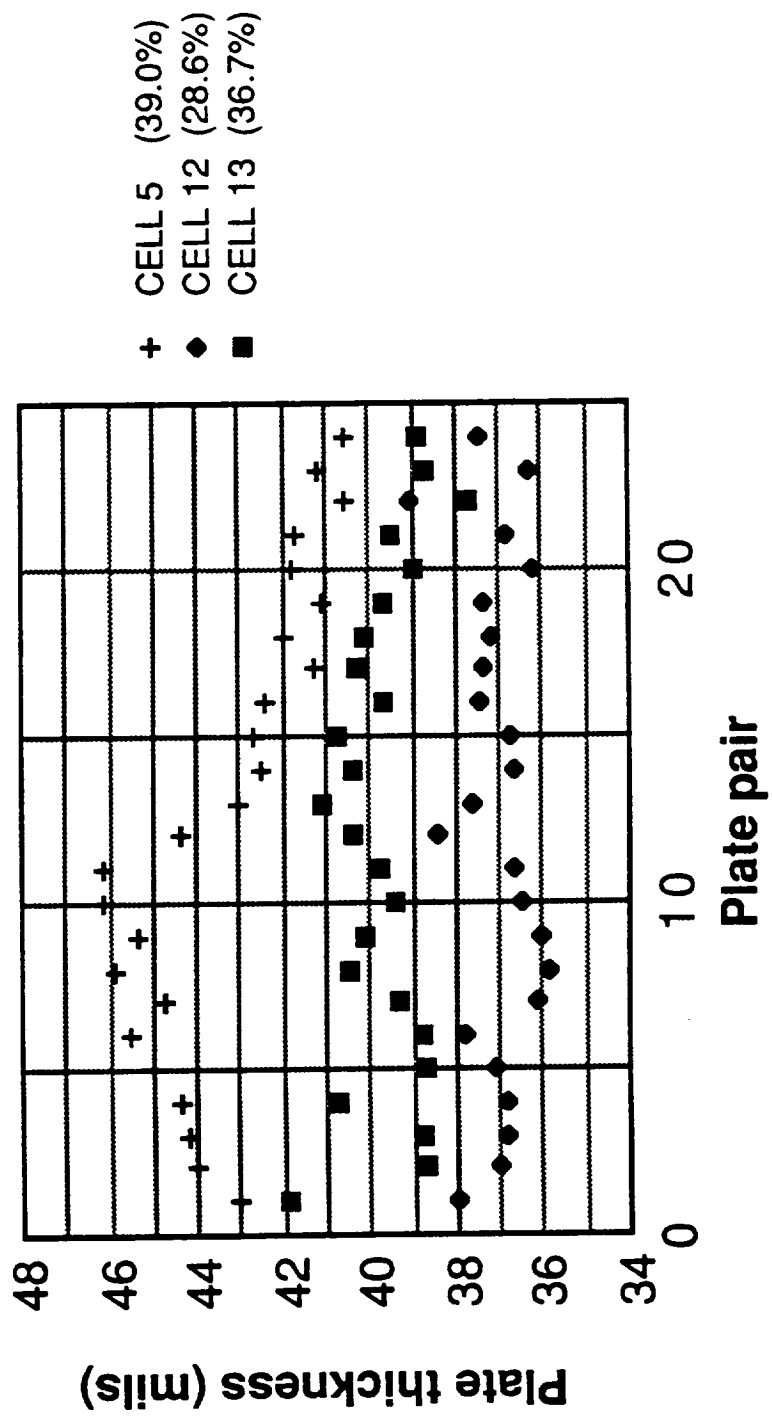


Figure 3 Plate thickness in DPA cells



**Acceptance Performance
of
Engineering and Test Module Cells**

Table 2 ACCEPTANCE DATA, 28.6% vs 36.7%

PROPERTY	28.6% KOH (Avg. of 5 Cells)	36.7% KOH (Avg. of 5 Cells)
Capacity at 0°C	102.07 Ah	110.47 Ah
Capacity at 10°C	94.05 Ah	104.39 Ah
Capacity at 20°C	83.85 Ah	95.15 Ah
Charge Retention 72h, 20°C	78.83/98.73 --->79.8%	91.38/107.68-->84.9%

Figure 4 RNH-90-3 EM-2 ACCEPTANCE TEST
 OC Capacity Test
 SECOND CYCLE CHARGE, May 5, 1988

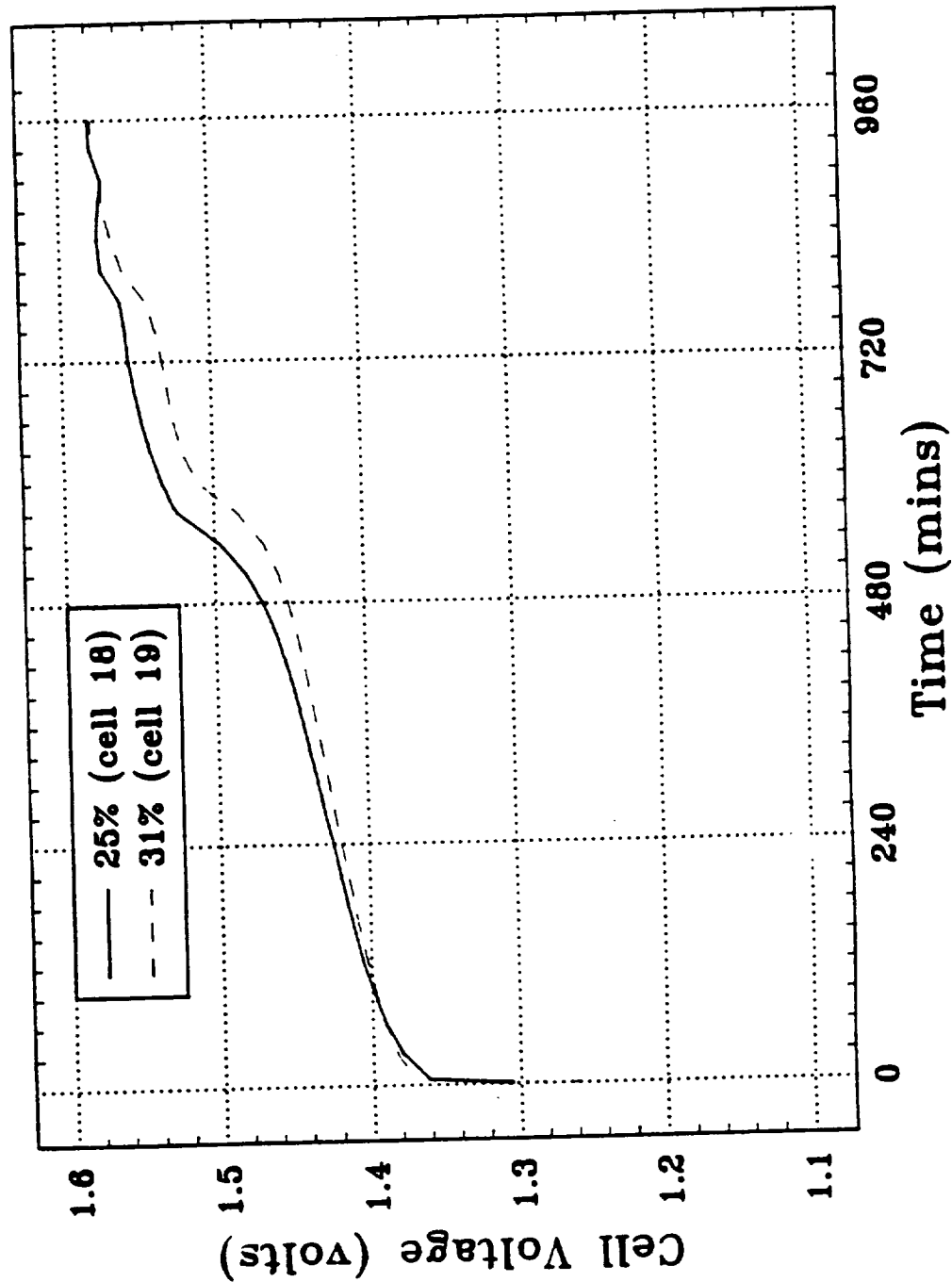


Figure 5 RNH-90-3 EM-2 ACCEPTANCE TEST
 OC Capacity Test
 SECOND CYCLE DISCHARGE and SHORT DOWN
 May 5, 1988

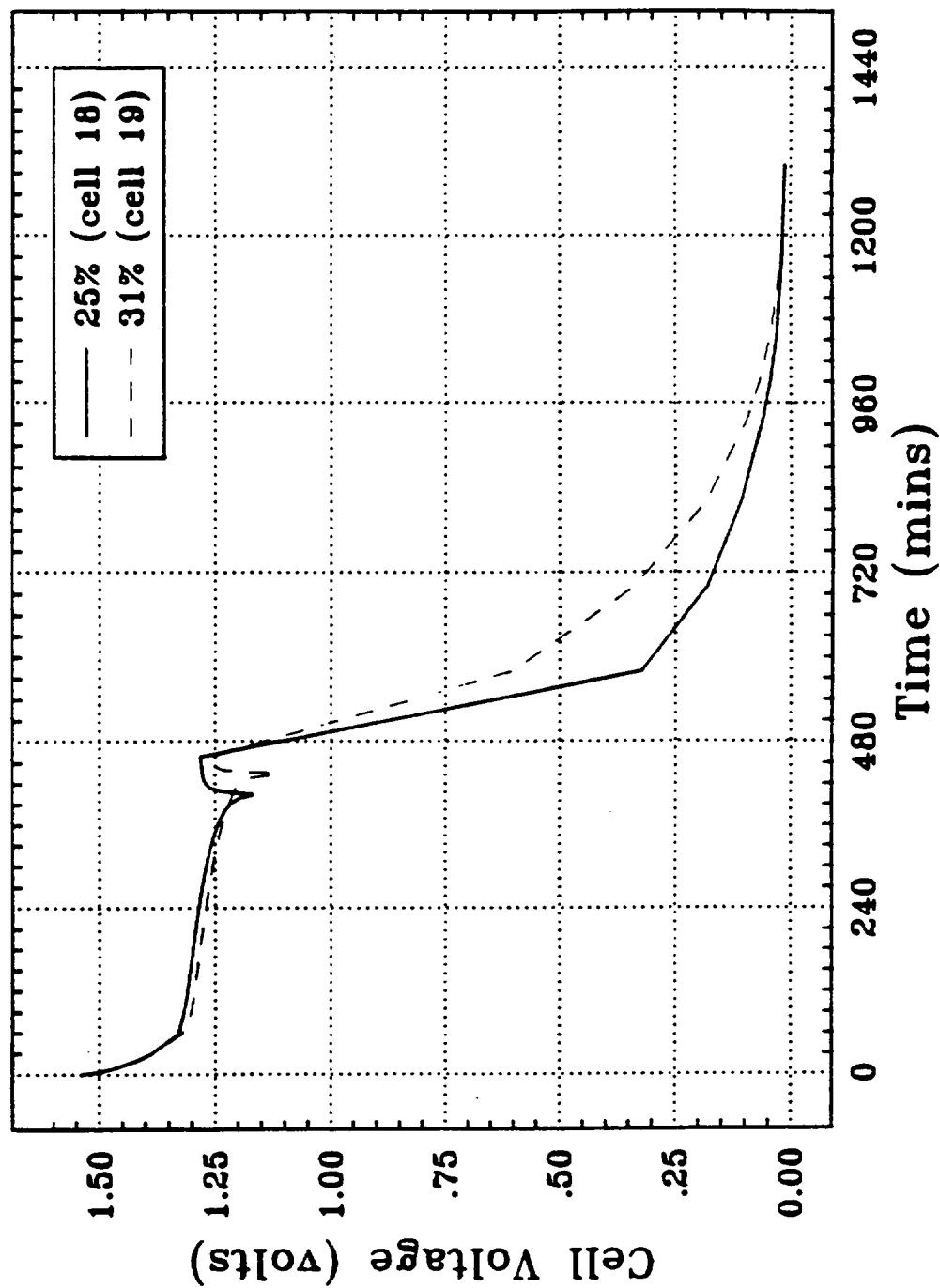


Figure 6 RNH-90-3 EM-2 ACCEPTANCE TEST
 10C Capacity Test
 SECOND CYCLE CHARGE, May 5, 1988

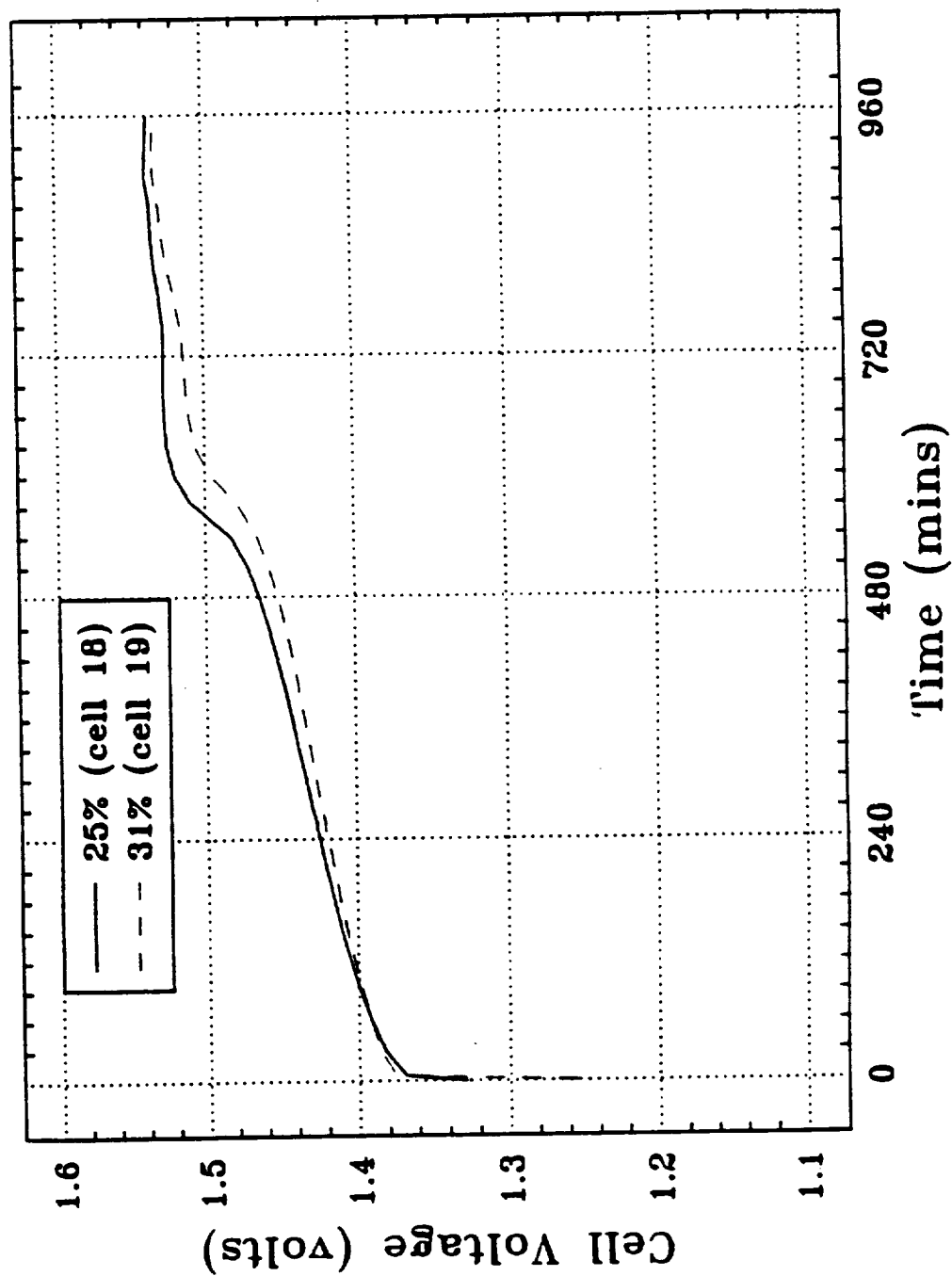


Figure 7 RNH-90-3 EM-2 ACCEPTANCE TEST
10C Capacity Test
SECOND CYCLE DISCHARGE and SHORT DOWN
May 5, 1988

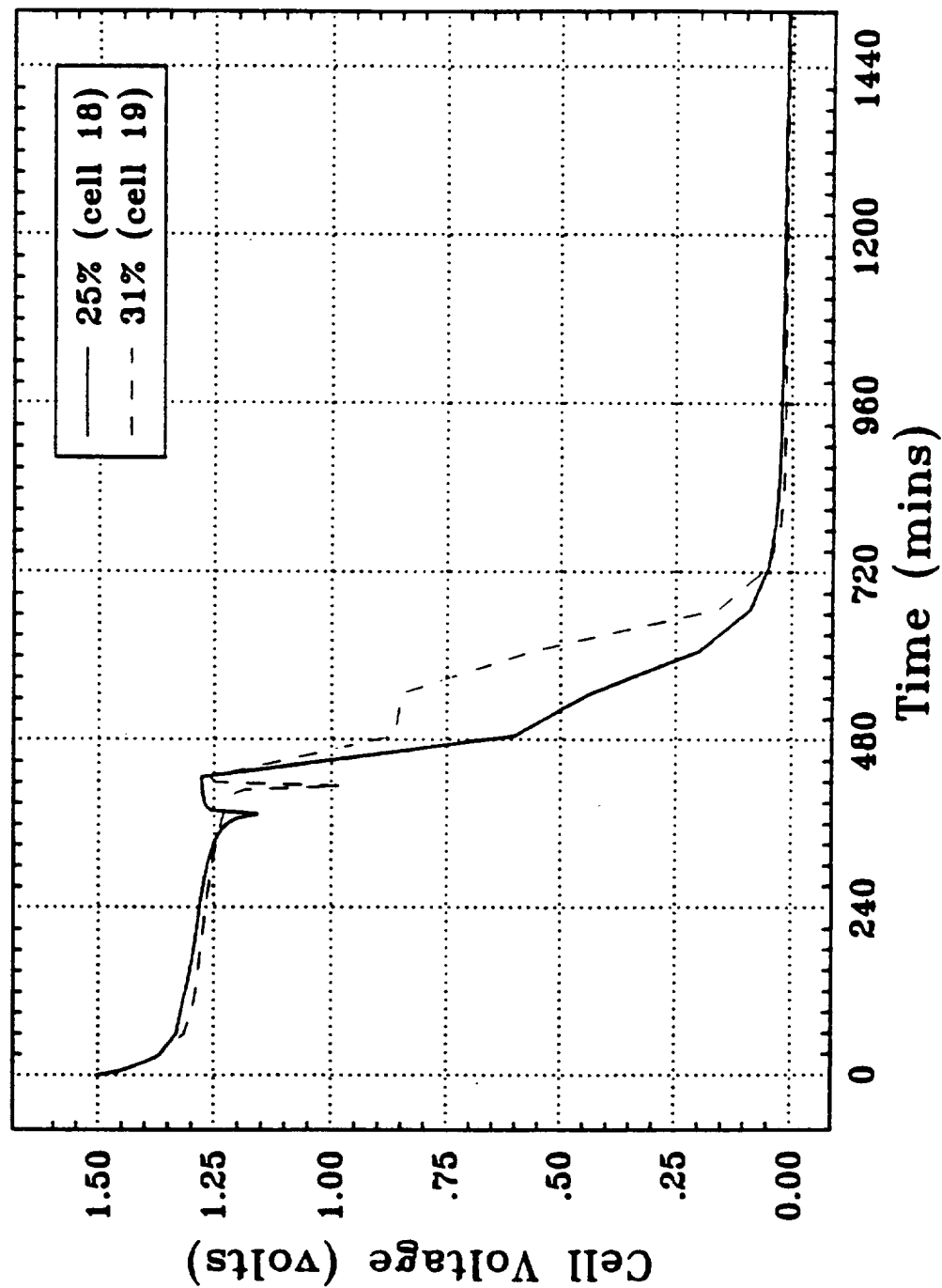


Figure 8 RNH-90-3 EM-2 ACCEPTANCE TEST
 20C Capacity Test
 SECOND CYCLE CHARGE, May 5, 1988

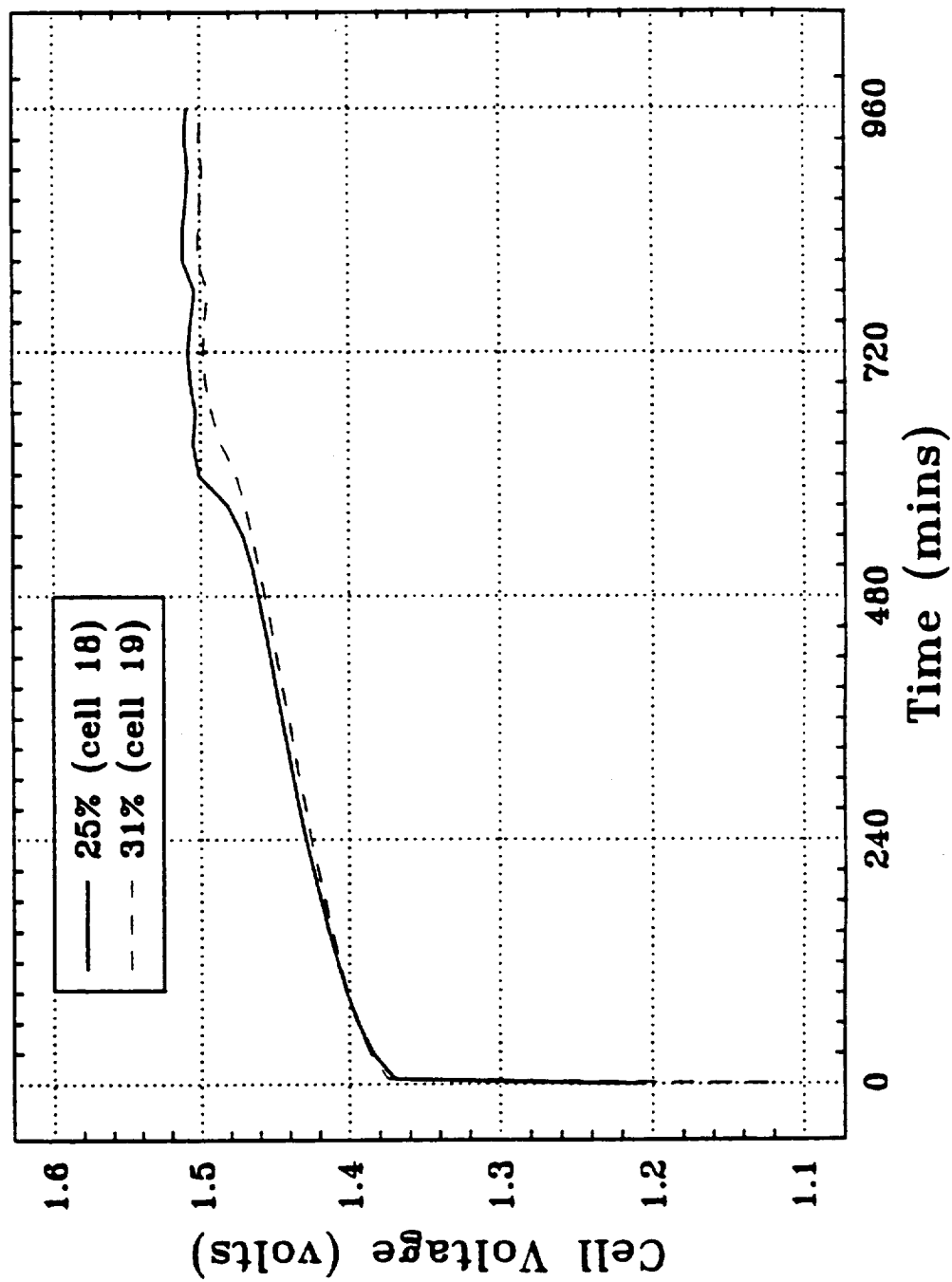


Figure 9 RNH-90-3 EM-2 ACCEPTANCE TEST
20C Capacity Test
SECOND CYCLE DISCHARGE and SHORT DOWN
May 5, 1988

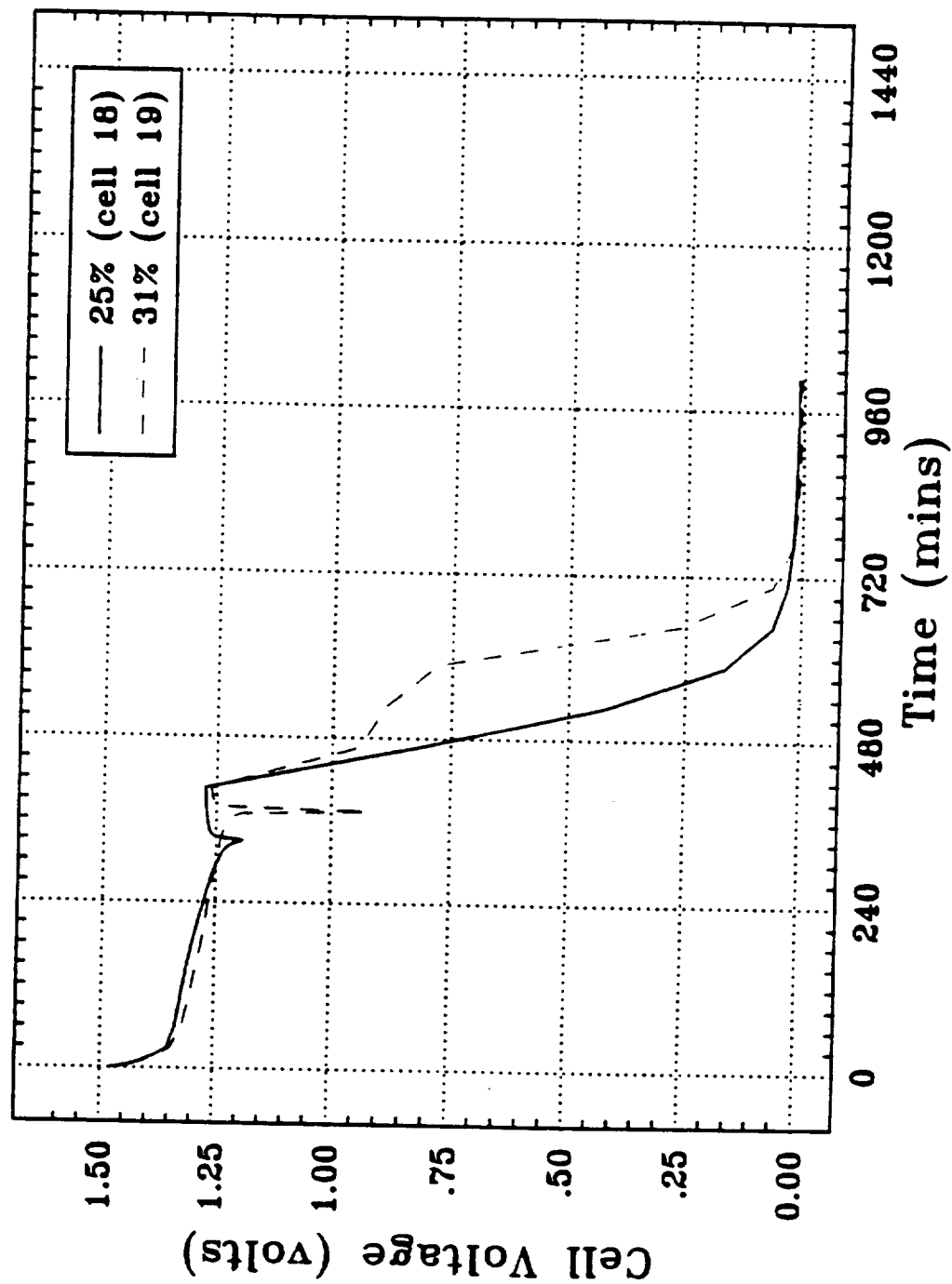


Figure 10 End-of-Charge Pressures during Acceptance

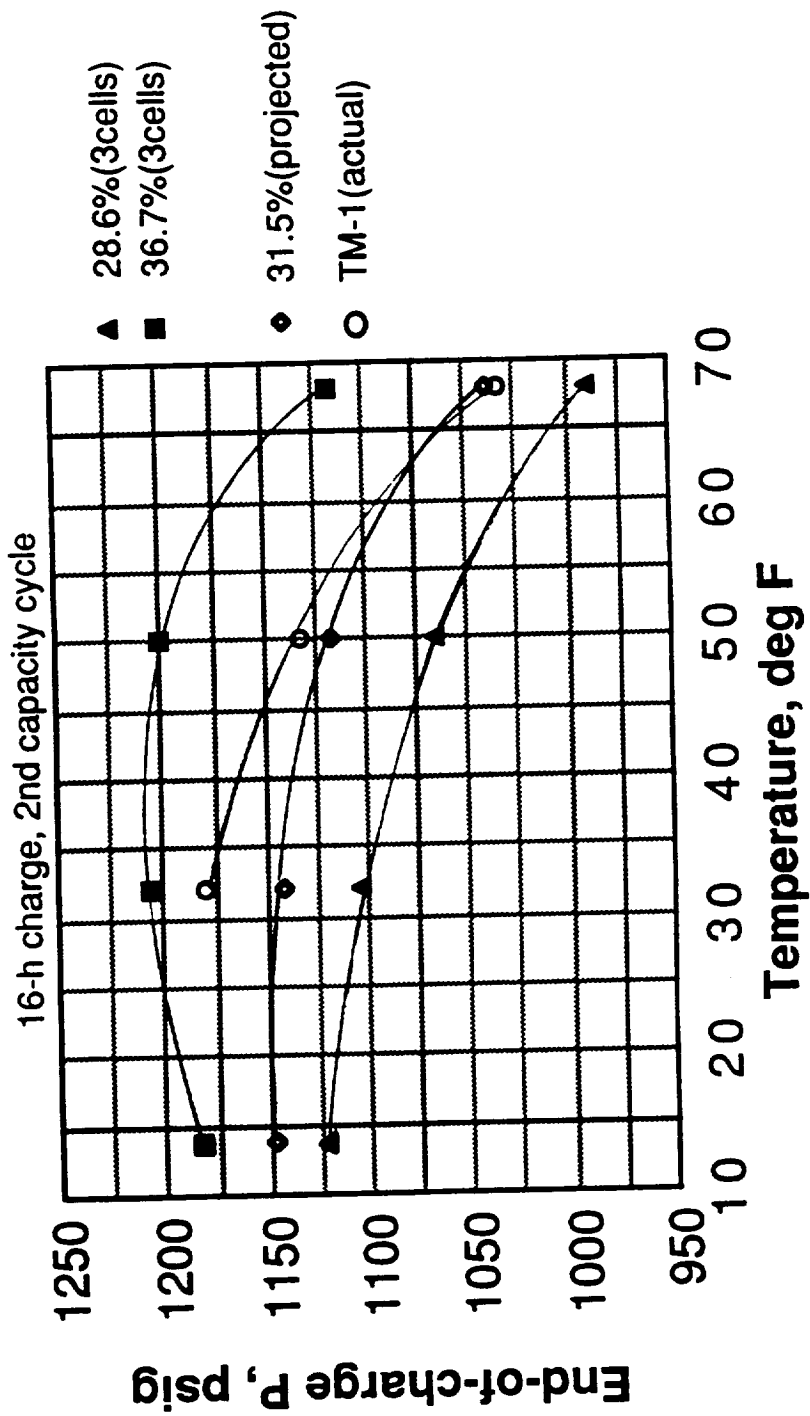
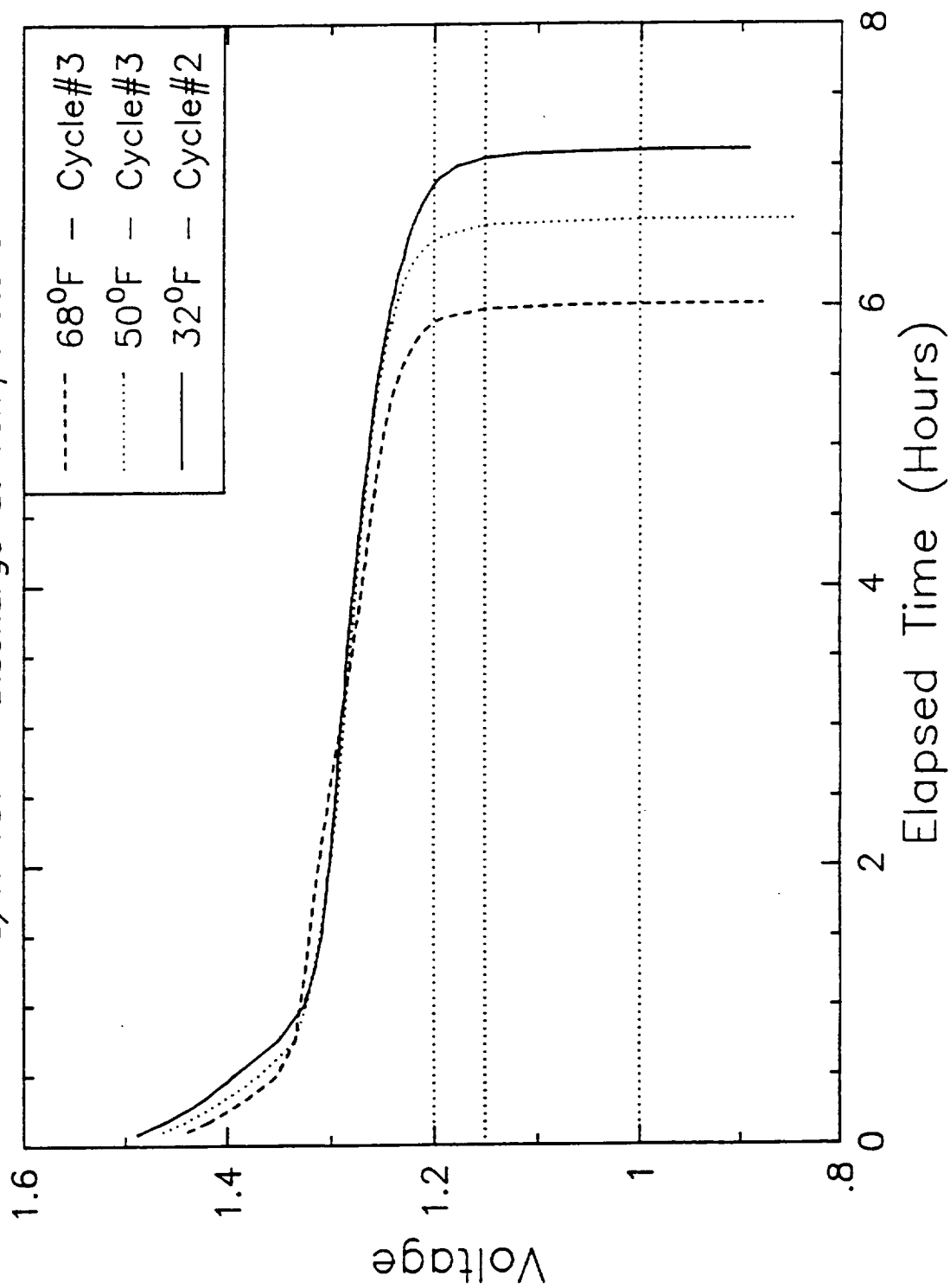


Table 3 HST NIH2 ATP TEST DATA SUMMARY

TEST ARTICLES	2ND CAP AT 32°F			2ND CAP AT 50°F			2ND CAP AT 68°F		
	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX
86 TM-1 (31%)	100.7	104.1	106.9	93.0	96.2	98.9	82.9	85.9	88.0
82 TM-2 (31%)	99.2	104.2	106.5	90.7	93.7	96.7	81.5	84.8	87.5
3 EM-2 (29%)	101.7	102.1	102.5	93.4	94.0	94.3	82.5	83.2	84.0

Figure 11 RNH-90-3 TM1
ACCEPTANCE TEST PROCEDURE
S/N 107 - Discharge at Temperature



Self-Discharge

Figure 12 EM-1 Self-Discharge at 24 deg C

after short-down and chg. @ 0 deg C

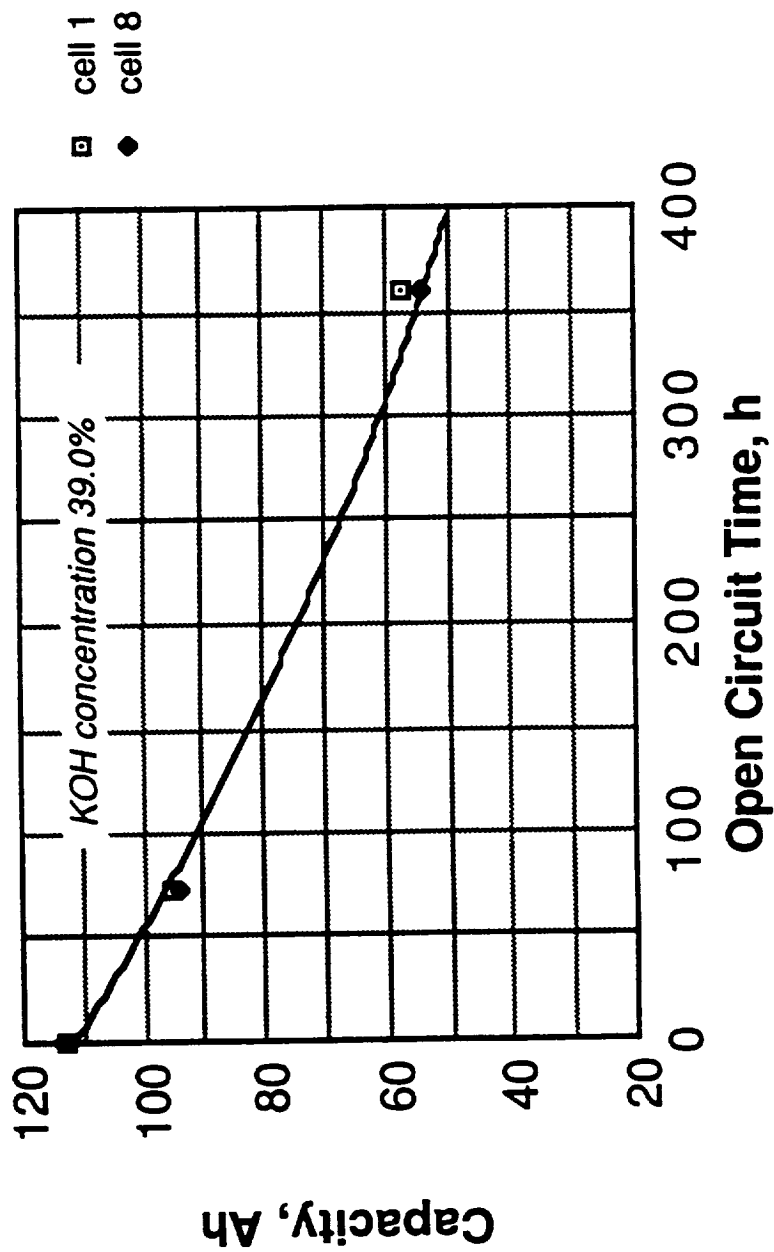


Figure 13 EM-2 Self-Discharge at 24 deg C

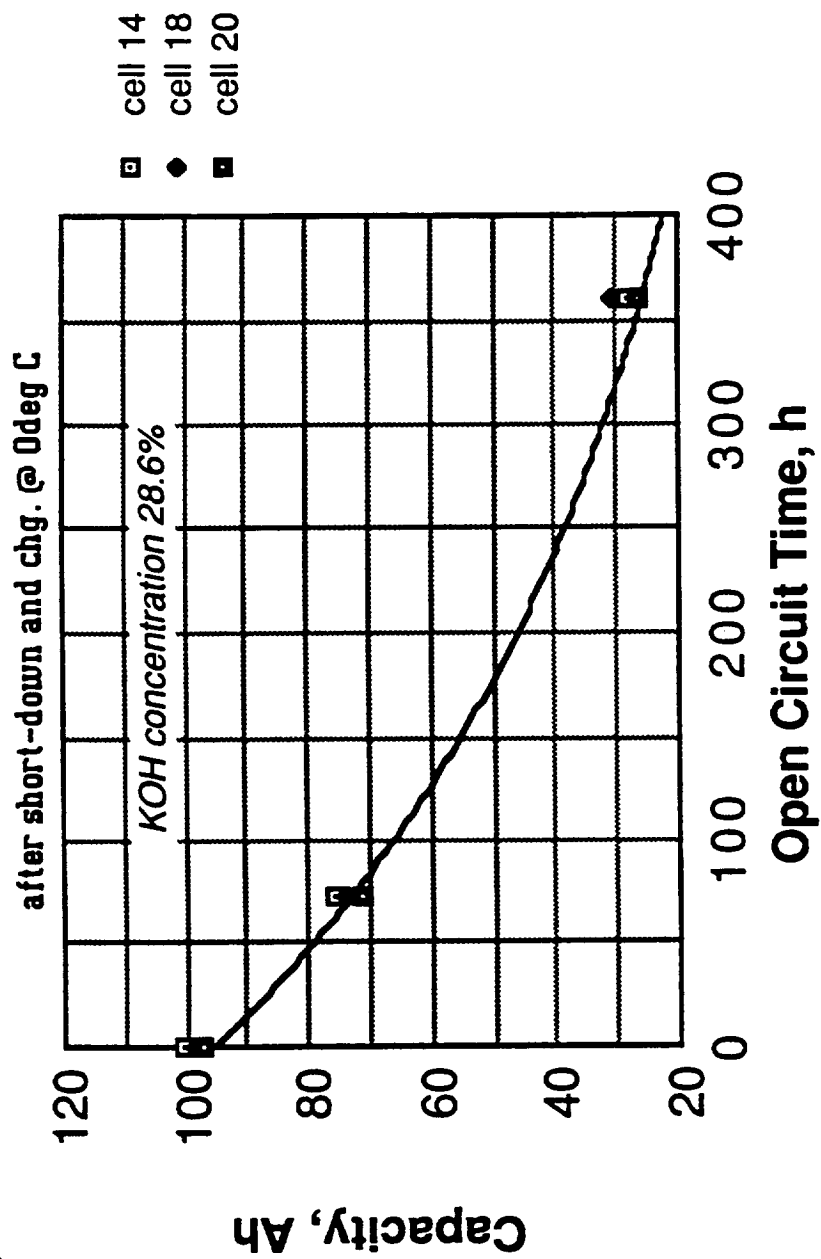


Figure 14 EM-2 Self-Discharge at 24 deg C

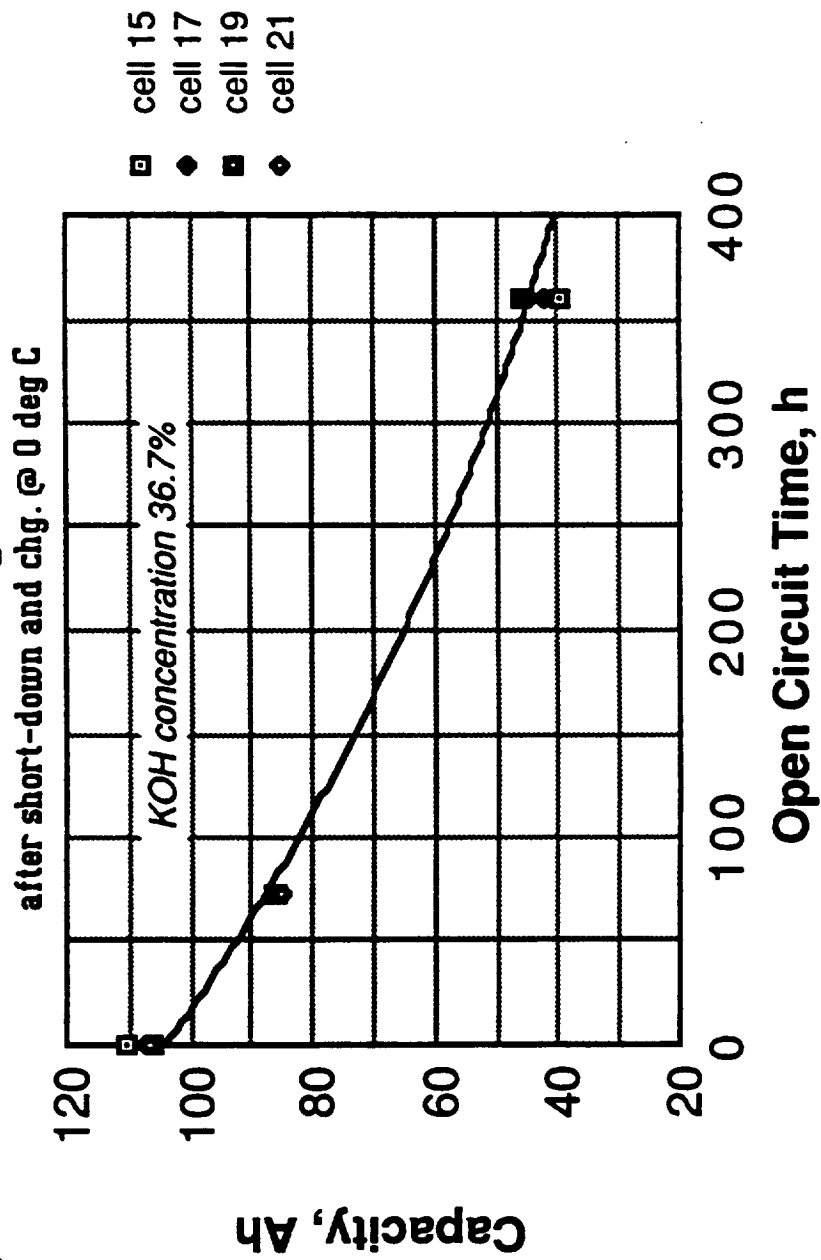
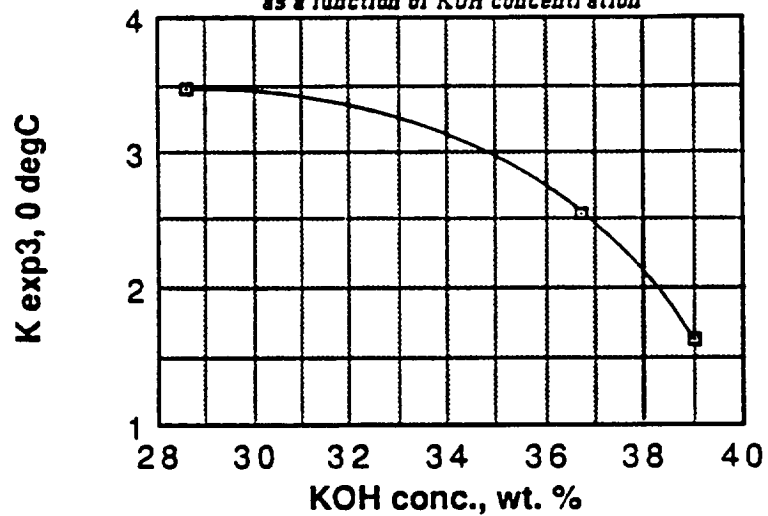


Figure 15 Self-Discharge Rate Constant
as a function of KOH concentration



Low-Earth Orbital Cycling Tests

Table 4 CHARGE RETURN DURING TRICKLE CHARGE 0°C,
FOLLOWING CHARGE AT 9.3A TO 1.52V

<u>Run No.</u>	<u>Cell No.</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>17</u>	<u>19</u>	<u>21</u>
1.	Baseline cap.	68.0	68.5	68.0	68.16	66.5	66.9
2.	.5h, .5A (.25Ah in)	68.1	68.6	68.2	67.6	65.9	66.4
	△ to baseline	+.1	+.1	+.2	-.56	-.6	-.5
	Tr. ch. efficiency	40%	40%	80%	--	--	--
3.	1.0h, .5A (.5Ah in)	68.2	68.8	68.3	67.9	66.2	66.5
	△ to baseline	+.2	+.3	+.3	-.26	-.3	-.4
	Tr. ch. efficiency	40%	60%	60%	--	--	--
4.	5.0h, .5A (2.5Ah in)	69.4	69.7	69.1	68.7	67.2	67.5
	△ to baseline	+1.4	+1.2	+1.1	+.54	+.7	+.6
	Tr. ch. efficiency	56%	48%	44%	22%	28%	24%
5.	.2h, 3.0A (.6Ah)	68.8	69.5	69.1	68.0	66.3	66.7
	△ to baseline	+.8	+1.0	+1.1	-.16	-.2	-.2
	Tr. ch. efficiency	125%	166%	183%	--	--	--
6.	.5h, 3.0A (1.5Ah)	69.7	70.3	69.9	69.0	67.4	67.7
	△ to baseline	+1.7	+1.8	+1.9	+.74	+.9	+.8
	Tr. ch. efficiency	113%	120%	127%	49%	60%	53%

Table 5 CHARGE RETURN DURING TRICKLE CHARGE 24°C,
FOLLOWING 16 H CHARGE AT 9.3A

<u>Run No.</u>	<u>Cell No.</u>	<u>16</u>	<u>18</u>	<u>20</u>	<u>17</u>	<u>19</u>	<u>21</u>
1.	Baseline cap.	82.4	82.0	81.6	91.3	90.9	91.5
2.	24h, .5A (12 Ah in)	79.8	78.6	76.3	91.8	91.0	91.8
	Δ to baseline	-2.6	-3.4	-5.3	+.5	+.1	+.3
	Tr. ch. efficiency	<0%	<0%	<0%	~0%	~0%	~0%
3.	96h, .5A (48 Ah in)	80.0	78.7	78.3	90.1	89.4	89.6
	Δ to baseline	-2.4	-3.3	-4.1	-1.2	-1.5	-1.9
	Tr. ch. efficiency	<0%	<0%	<0%	<0%	<0%	<0%
4.	24h, .25A (6 Ah in)	76.5	75.1	72.4	85.6	85.3	86.0
	Δ to baseline	-5.9	-6.9	-9.2	-5.7	-5.6	-5.5
	Tr. ch. efficiency	<0%	<0%	<0%	<0%	<0%	<0%

Figure 16 EM-1 Orbital Cycling Performance

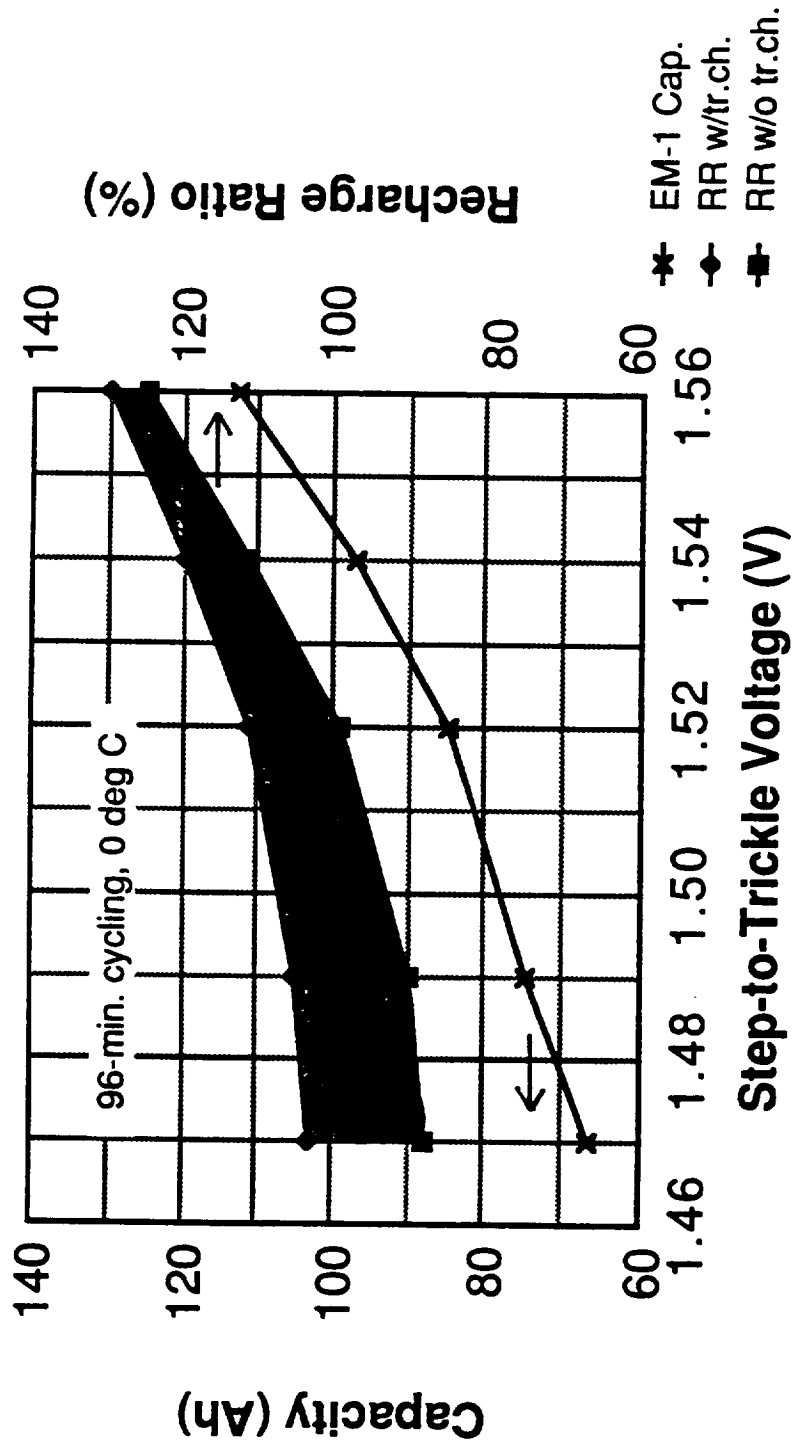


Figure 17 EM-2 Orbital Cycling Performance

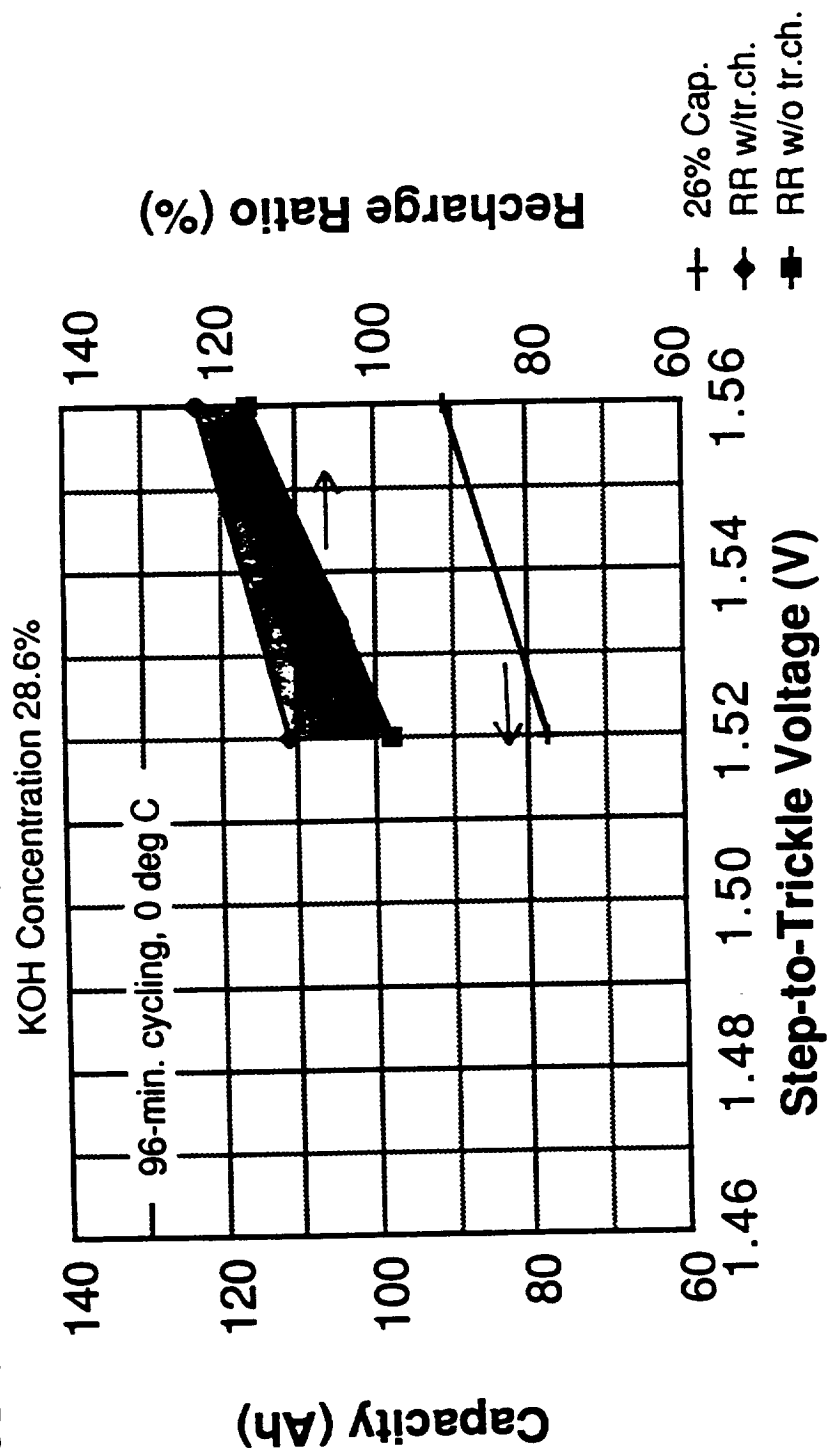
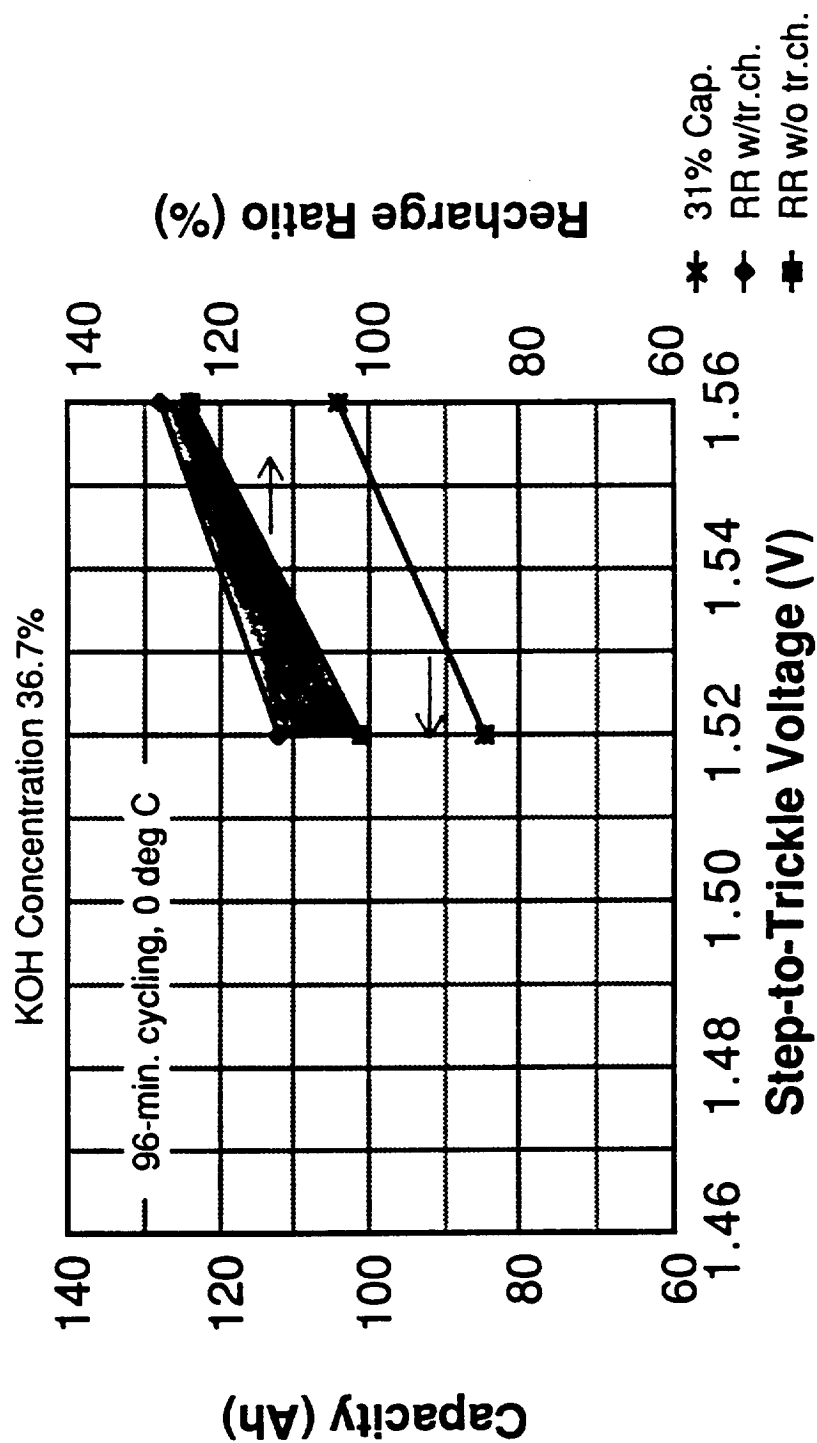


Figure 18 EM-2 Orbital Cycling Performance





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NASA BATTERY WORKSHOP

NASA GODDARD SPACE FLIGHT CENTER

ISSUES REGARDING STRUCTURAL ASPECTS OF THE NiH_2 CELL

NOVEMBER 3, 1988

JOHN A ANDRASIK
QUALITY, MATERIALS & PROCESSES OFFICE
NASA LEWIS RESEARCH CENTER



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November 1-3, 1988

BACKGROUND

- A PRESSURE VESSEL IS A CONTAINER THAT STORES PRESSURIZED FLUIDS AND:
 - CONTAINS STORED ENERGY OF 14, 240 FT./LBS. (19,307 J) OR GREATER BASED ON ADIABATIC EXPANSION OF A PERFECT GAS; OR
 - CONTAINS A GAS OR LIQUID WHICH WILL CREATE A HAZARD IF RELEASED; OR
 - WILL EXPERIENCE A DESIGN LIMIT PRESSURE GREATER THAN 100 PSI

- THE NIH_2 CELL IS ESSENTIALLY A PRESSURE VESSEL
 - INTERNAL MAXIMUM CELL PRESSURE WILL APPROXIMATELY BE 1000 PSI FOR THE SPACE STATION LEO APPLICATION



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BACKGROUND. CONT'D.

- PRESSURE VESSELS DESIGNED FOR (MANNED) AEROSPACE APPLICATIONS MUST MEET SPECIFIC REQUIREMENTS
 - STANDARD GENERAL REQUIREMENTS FOR DESIGN AND OPERATION
 - PAYLOAD SAFETY
 - FRACITURE CONTROL
- CURRENT NIH_2 PRESSURE VESSEL ISSUES RESULT FROM THE INABILITY TO MEET THESE REQUIREMENTS IN SPECIFIC AREAS:
 - MATERIAL PROPERTIES
 - NONDESTRUCTIVE EVALUATION (NDE)
 - FAILURE MODE DETERMINATION
 - FABRICATION-INDUCED RESIDUAL STRESSES
 - ANALYTICAL ASSESSMENT TECHNIQUE (FRACTURE MECHANICS ANALYSIS)



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November 1-3, 1988

MATERIAL PROPERTIES

- PRESSURE VESSEL MATERIAL IS INCONEL 718
- NORMAL CELL OPERATION INCLUDES THE CYCLIC EVOLUTION/RECOMBINATION OF GASEOUS HYDROGEN AT HIGH PRESSURES
 - INTERNAL NIH_2 CELL ENVIRONMENT CONSISTS OF MORE THAN GASEOUS HYDROGEN
- NI-BASE SUPERALLOYS ARE CATEGORIZED AS BEING "EXTREMELY SUSCEPTIBLE" TO HYDROGEN ENVIRONMENT EMBRITTLEMENT (HEE)
- ISSUES
 - LACK OF INCONEL 718 MATERIAL PROPERTY TEST DATA RELATIVE TO NIH_2 OPERATING PARAMETERS
 - CELL PRESSURES
 - CELL ENVIRONMENT



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NDE

- GENERIC SPACE STATION NIH_2 CELL PRESSURE VESSEL DESIGN INCLUDES A CLOSURE WELD
- UNIQUE ASPECTS OF THIS GENERIC DESIGN PRECLUDES NORMAL NDE OF THE CLOSURE WELD
 - ELECTRODE STACK
 - WELD RING
- BOSS WELDS HISTORICALLY HAVE NOT BEEN COMPLETELY INSPECTED
- ISSUE
 - WELDS IN THE NIH_2 CELL PRESSURE VESSEL ARE NOT COMPLETELY INSPECTED



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FAILURE MODE DETERMINATION

- THE MANNER IN WHICH AN INITIAL FLAW WILL GROW THROUGH THE WALL OF A PRESSURE VESSEL MUST BE ASSESSED:
 - LEAD-BEFORE-BURST (NONHAZARDOUS); OR
 - LEAD-BEFORE-BURST (HAZARDOUS); OR
 - BRITTLE FAILURE
- THE FAILURE MODE CAN BE ANALYTICALLY MODELED (E.G., FLAGRO COMPUTER ALGORITHM)
 - VALID MATERIAL PROPERTY AND FLAW SIZE INPUTS ARE REQUIRED
 - A VALID ANALYTICAL MODEL IS REQUIRED
- THE FAILURE MODE CAN BE PHYSICALLY DEMONSTRATED
 - PRESSURE VESSEL(S) WITH FLAWS OF KNOWN SIZE AND ASPECT RATIOS IS (ARE) REQUIRED
 - DEMONSTRATION WILL BE VALID RELATIVE ONLY TO THOSE PRESSURE VESSELS TESTED



FAILURE MODE DETERMINATION, CONT'D.

- THE FAILURE MODE CAN BE DETERMINED VIA DUCTILE SCREENING(?)
- ISSUES
 - DIFFICULTIES EXIST WITH SUPPLYING REQUIRED INPUTS TO EITHER THE ANALYTICAL MODEL OR PHYSICAL DEMONSTRATION
 - UNKNOWN MATERIAL PROPERTIES
 - INCOMPLETE NDE
 - CONSIDERABLE DEBATE STILL RAGES REGARDING THE ACCEPTABILITY OF DUCTILE SCREENING WITHIN THE NASA FRACTURE MECHANICS COMMUNITY



RESIDUAL STRESS

- A STRESS THAT EXISTS IN A STRUCTURE AS MANUFACTURED WHICH IS DUE TO PROCESSING, FABRICATION, AND/OR PRIOR LOADING
 - EFFECTS MAY BE ADDITIVE TO OPERATING STRESSES
- TECHNIQUES EXIST TO ASSESS STRUCTURAL RESIDUAL STRESSES
 - DESTRUCTIVE
 - NONDESTRUCTIVE
- RESIDUAL STRESSES ARE PRESENT IN N₂H₄ PRESSURE VESSEL
 - MAGNITUDE AND DIRECTIONALITY ARE UNKNOWN
- ISSUE
 - SAFE-LIFE VERIFICATION IS QUESTIONABLE IF RESIDUAL STRESSES ARE NOT CONSIDERED
- HISTORICALLY HAVE NOT BEEN ASSESSED



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ANALYTICAL ASSESSMENT TECHNIQUE

- NASA SPACEFLIGHT COMMUNITY GENERICALLY APPLIES LINEAR ELASTIC FRACTURE MECHANICS ANALYSIS IN FRACTURE CONTROL APPLICATIONS
 - FLAGRO FAMILY OF COMPUTER CODES
- THIN-WALL PRESSURE VESSEL FABRICATED FROM "TOUGH" METALLIC MATERIALS (E.G., INCONEL 718) TYPICALLY FAIL (FRACTURE) IN AN ELASTIC-PLASTIC MANNER
 - ELASTIC-PLASTIC FRACTURE MECHANICS IS IN ITS INFANCY
- ISSUE
 - DEBATE EXISTS REGARDING THE CONSERVATISM OF LINEAR ELASTIC FRACTURE MECHANICS ANALYSIS (FLAGRO) WHEN APPLIED TO THIN-WALL PRESSURE VESSELS



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NASA/LEWIS CURRENT ACTIVITIES SUMMARY

- MATERIAL TEST PROGRAM
 - POSSIBLE FUNDING THROUGH WP-04 SPACE STATION PROGRAM OFFICE (\$80K)
- NDE OF CLOSURE WELD
 - SAMPLES SIMULATING NiH_2 CLOSURE WELD FABRICATED AT LERC AND FORWARDED TO NASA NDE PERSONNEL FOR EVALUATION (APPROXIMATELY \$1K IN MANHOURS)
 - SCOPE OF ACTIVITIES IS TO IDENTIFY MOST PROMISING NDE TECHNIQUE(S) FOR FURTHER DEVELOPMENT
- RESIDUAL STRESS ANALYSIS
 - PRESSURE VESSEL PURCHASED FROM NiH_2 CELL MANUFACTURER (\$1.75K)
 - SOURCE FOR NEUTRON DIFFRACTION IDENTIFIED - PR RELEASED (\$8.5K)
 - SAMPLES ASSESSED VIA X-RAY DIFFRACTION

C-5.



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RECOMMENDATIONS

- INCREASE IN SCOPE OF ACTIVITIES
 - CURRENT ACTIVITIES UNDERWAY AT NASA/LEWIS WILL NOT SOLVE (ALL OF) THE ISSUES
 - NIH₂ USERS SHOULD ORGANIZE EFFORTS
- ADDRESS THE ISSUES IDENTIFIED DIRECTLY
- BEWARE OF MANNED SPACEFLIGHT REQUIREMENTS

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HUGHES AIRCRAFT COMPANY

EFFECT OF PRECHARGE ON Ni/H₂ CELL STORAGE CAPACITY

**H. S. LIM AND S. J. STADNICK
HUGHES AIRCRAFT COMPANY**

TYPES OF PRECHARGE OF Ni/H₂ CELLS

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H₂ PRECHARGE:

EXCESS OF H₂ IN CELL

NICKEL PRECHARGE:

DEFICIT OF H₂ IN CELL

PRECHARGE AND REVERSAL ELECTRODE REACTIONS

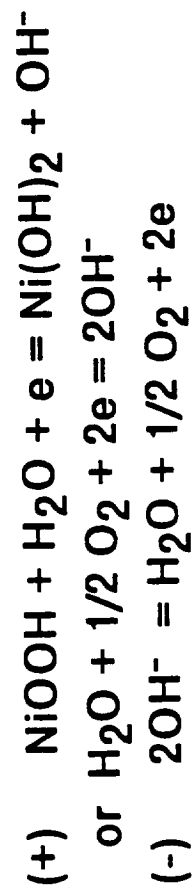
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H₂ PRECHARGE CELL:



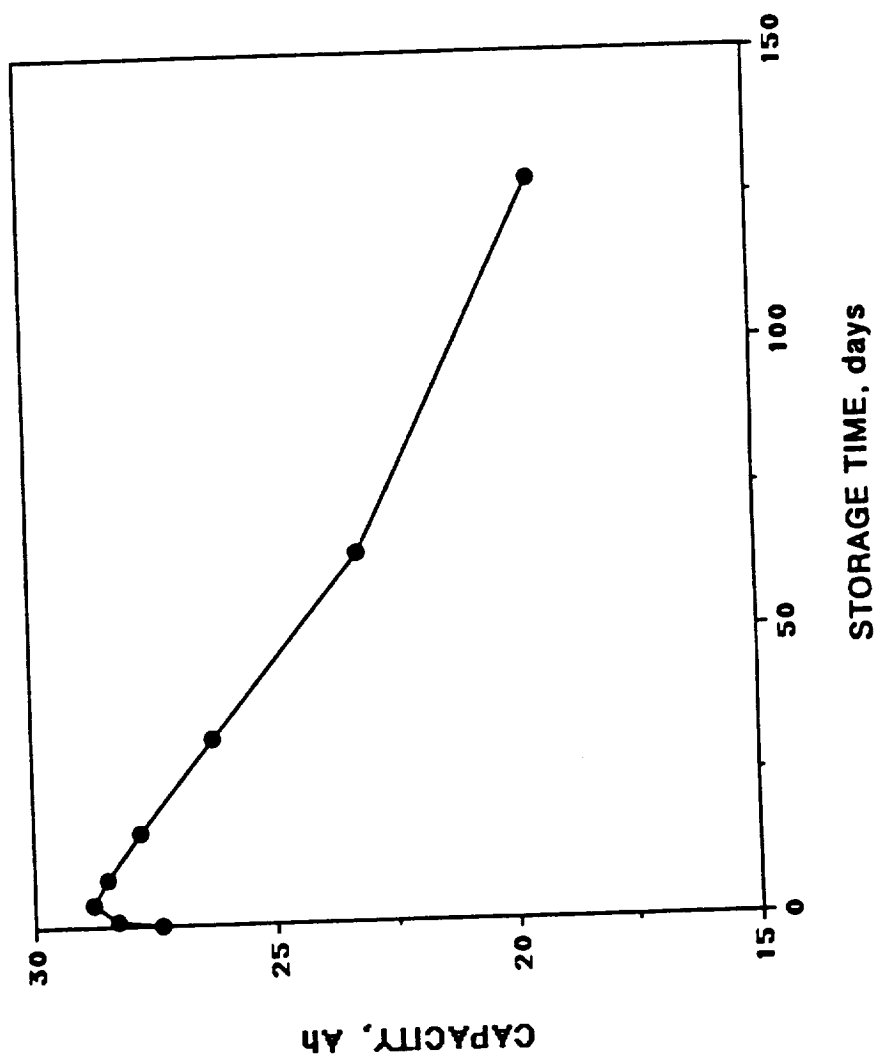
NICKEL PRECHARGE CELL:



CAPACITY FADING OF Ni/H₂ CELL ON OPEN CIRCUIT STORAGE

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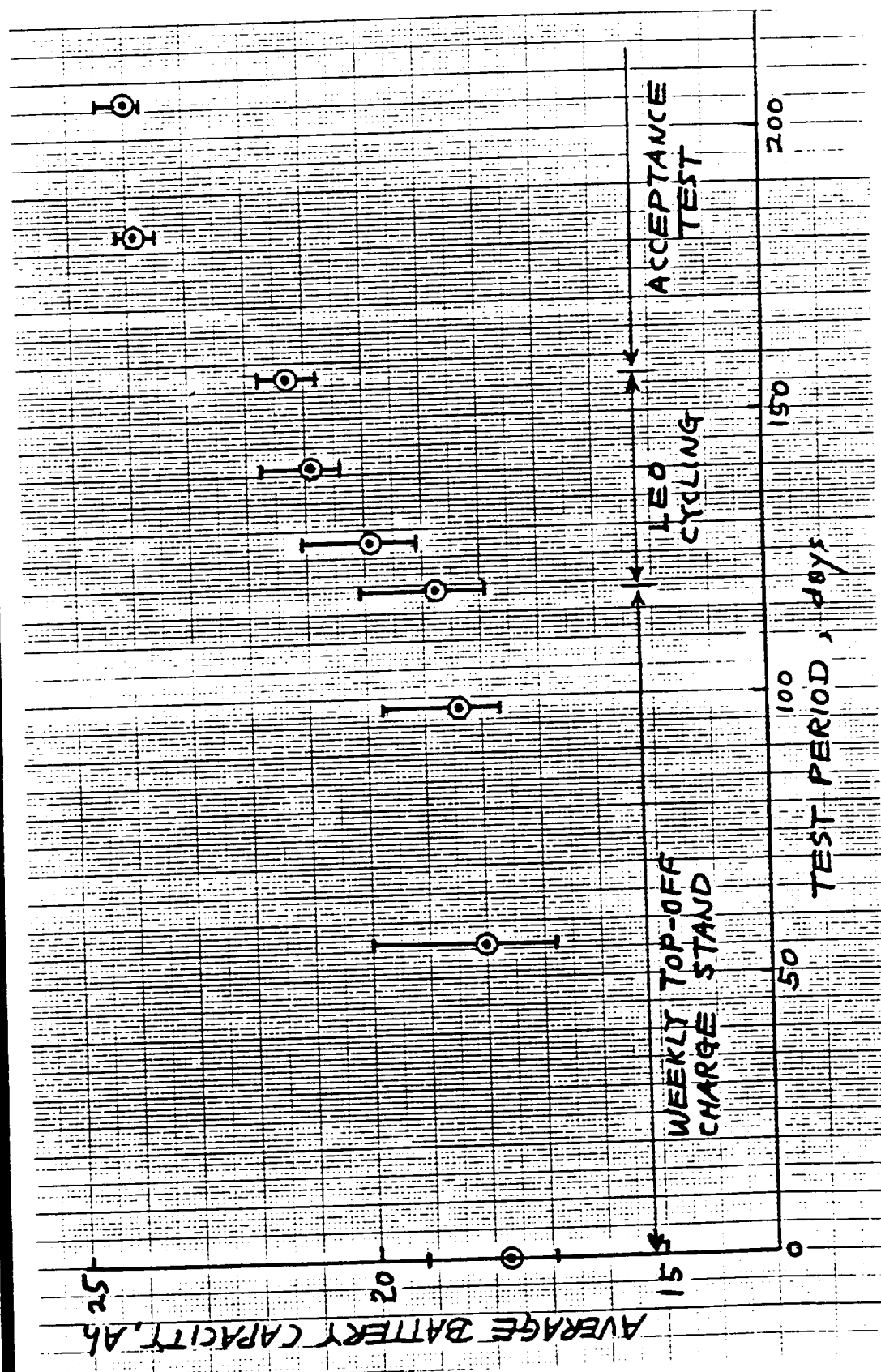
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RECOVERY OF FADED CAPACITY OF A Ni/H_2 CELL

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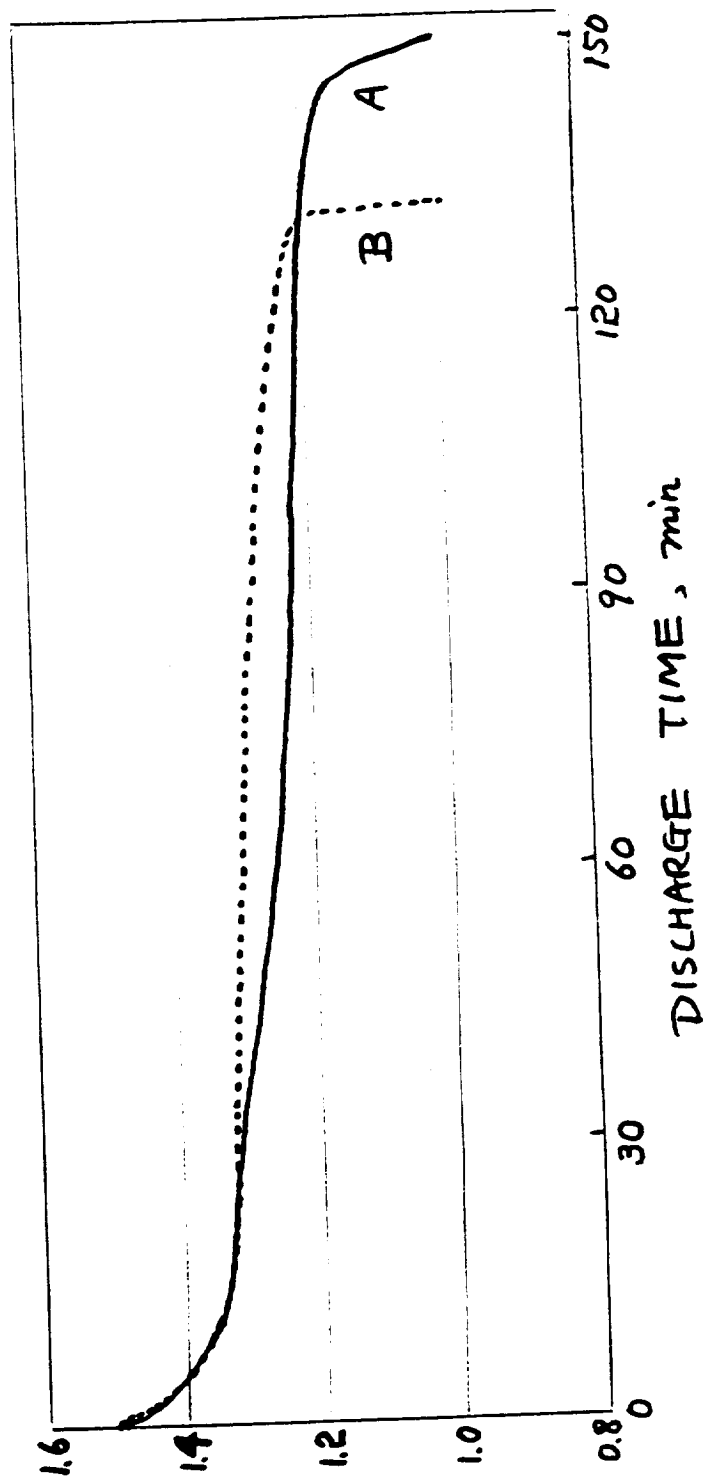
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DISCHARGE VOLTAGE OF HEALTHY AND CAPACITY FADED CELLS

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A: CELL WITHOUT CAPACITY LOSS
B: CELL WITH CAPACITY LOSS



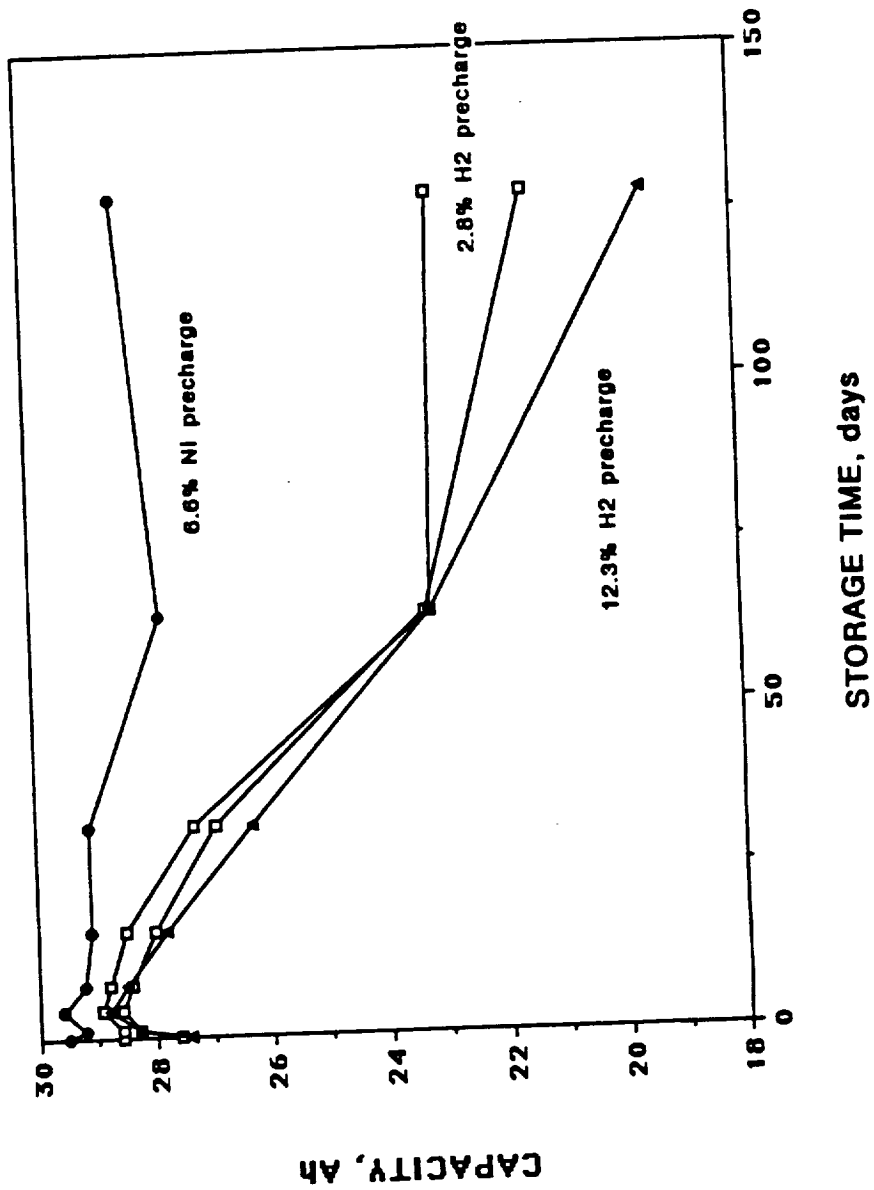
CELL PRESSURE OF HEALTHY AND CAPACITY FADED CELL

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Pack No.	Capacity, Ah	EOCP, psig	EODP, psig
Q3	50.62	766-742	221-256
Q4	52.42	742-736	190-202
F001	44.83	774-782	273-301
F002	44.94	749-771	280-303
F003	45.82	746-780	267-308
F004	45.01	714-760	237-299

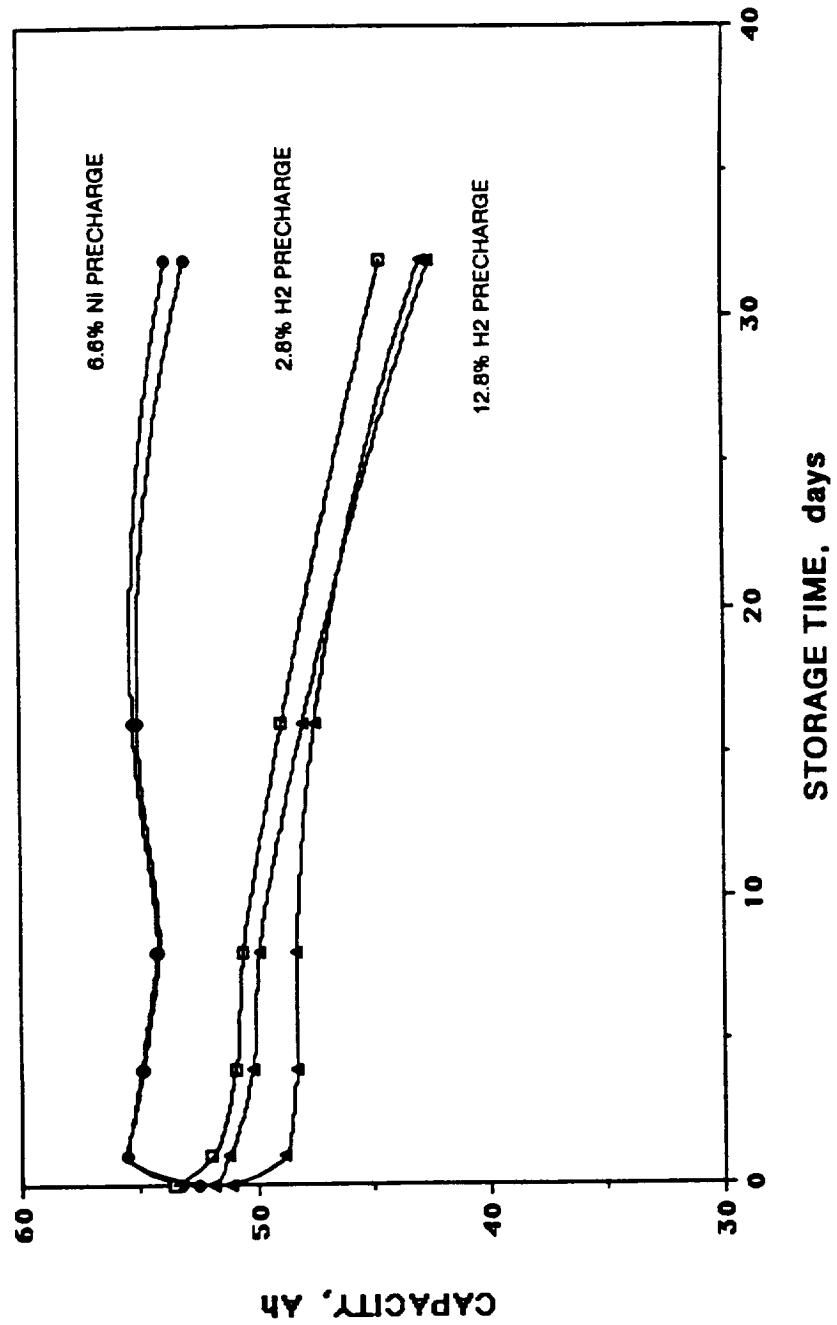
EFFECT OF PRECHARGE ON CAPACITY FADING



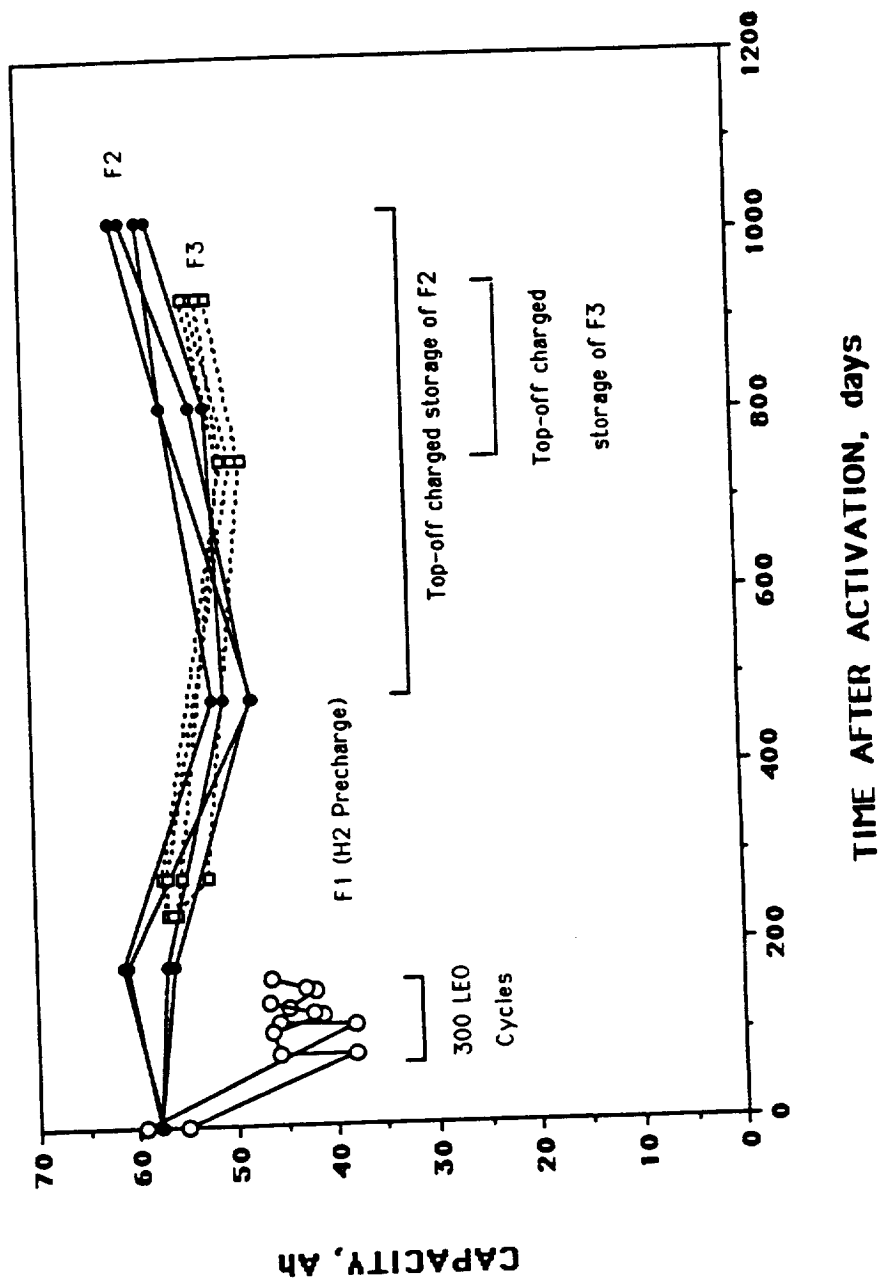
EFFECT OF PRECHARGE ON CAPACITY FADING

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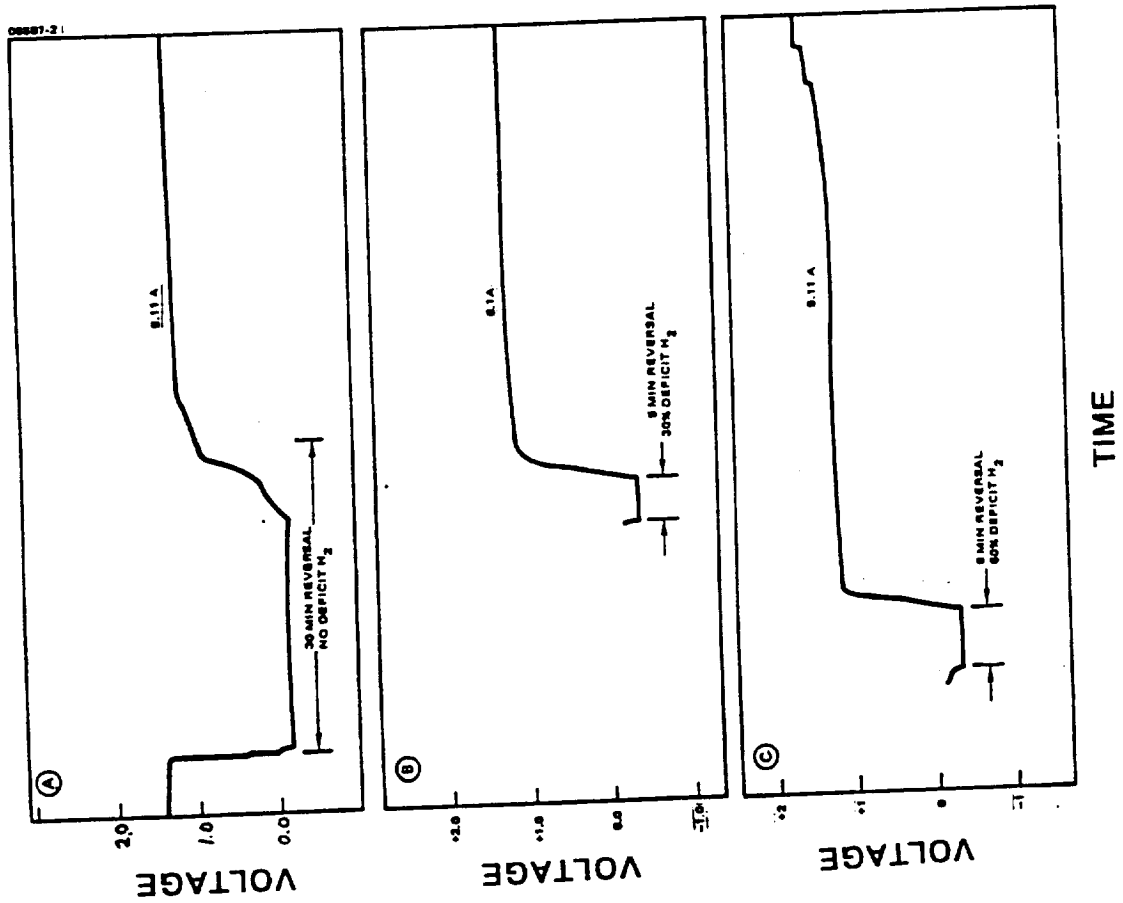
PRECHARGE EFFECT ON CAPACITY FADING OF I-6 FLIGHT BATTERIES



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RESEARCH LABORATORIES

Ni/H₂ CELL VOLTAGES DURING REVERSAL

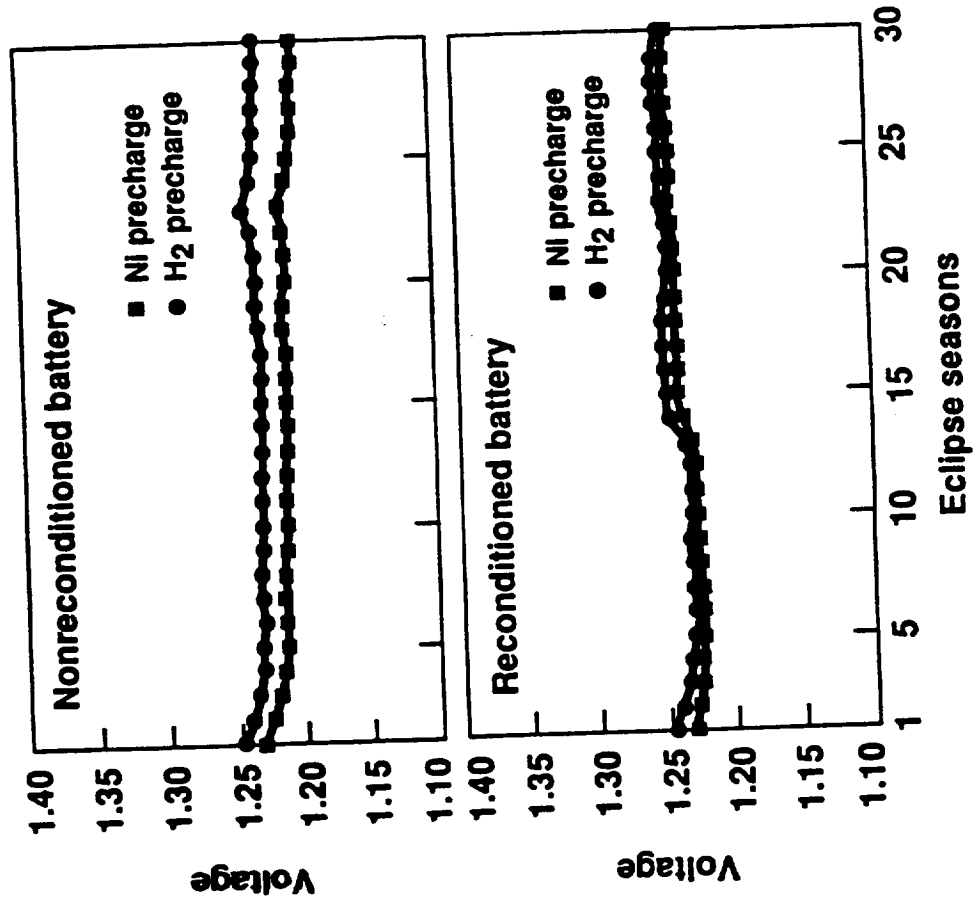


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Voltage at End of Discharge, Eclipse Day 23

Ni vs H₂ Precharge

M86627-4



POSSIBLE MECHANISM OF CAPACITY FADING

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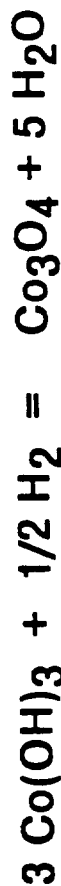
ASSUMPTION: ACTIVE Co IS NEEDED FOR HIGH
ACTIVE MATERIAL UTILIZATION

ACTIVE Co IS CoOOH OR Co(OH)₃

CHEMICAL REACTIONS DURING STORAGE:



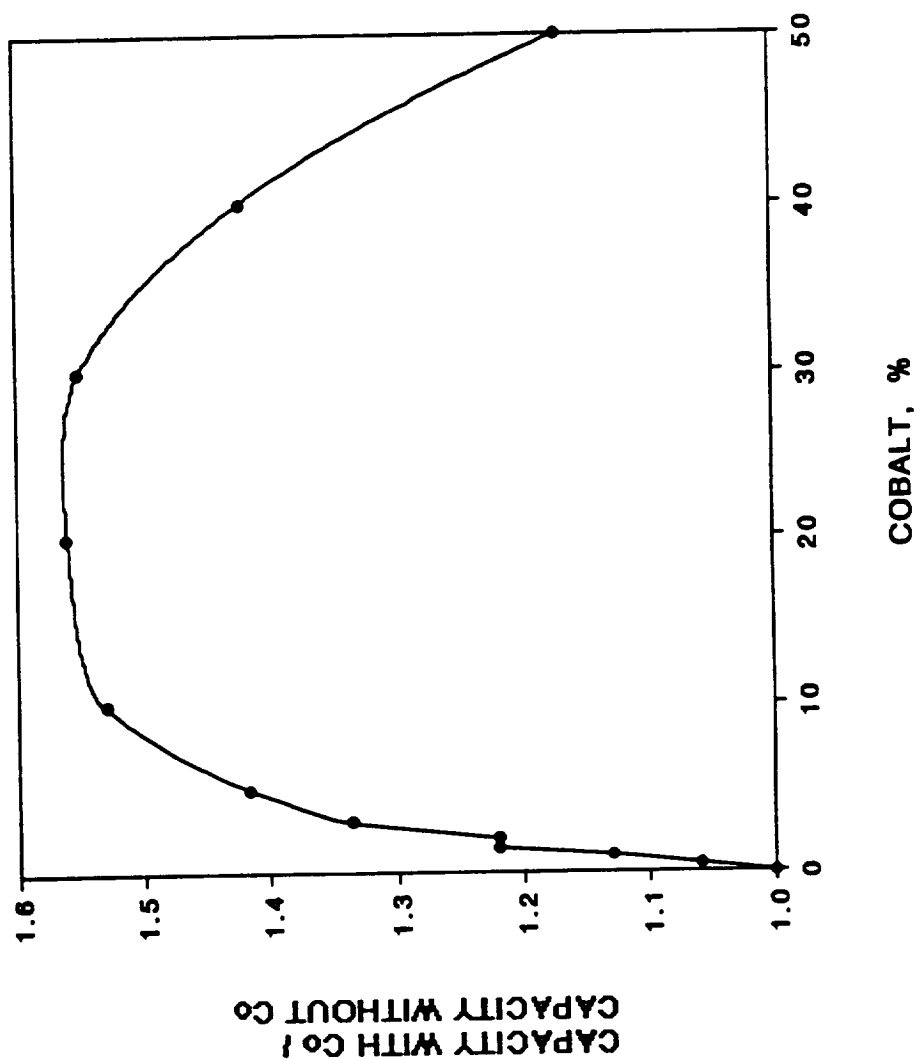
OR



EFFECT OF COBALT ON NICKEL ELECTRODE CAPACITY

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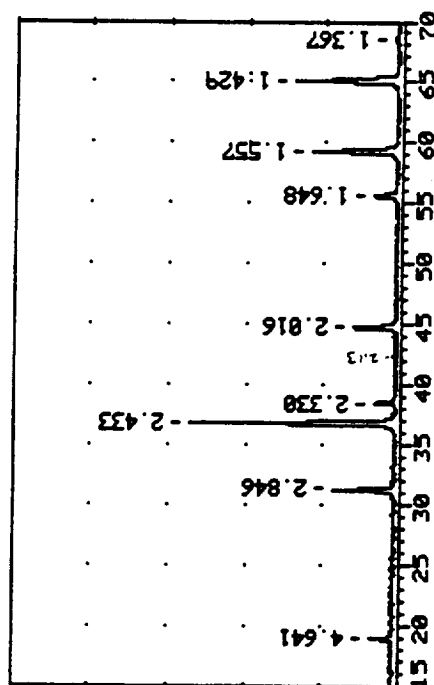


S. Januszkiewicz, 1959

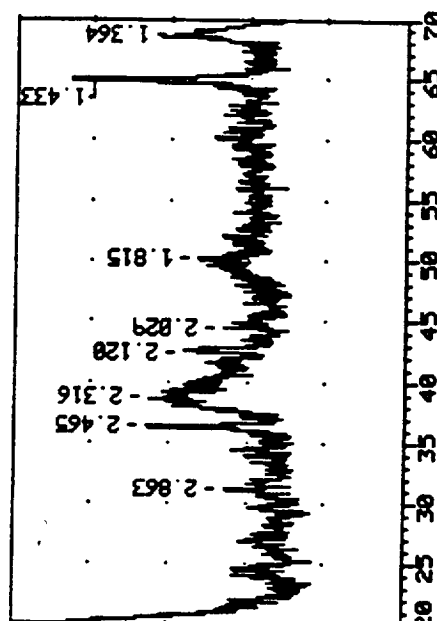
X-RAY DIFFRACTION PATTERNS Co₃O₄ AND BROWN RESIDUE FROM Ni ELECTRODE

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(A)



(B)

CONCLUDING REMARKS

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- CAPACITY OF Ni/H₂ CELLS (31% KOH) DID NOT FADE IF SUFFICIENT AMOUNT OF Ni PRECHARGE IS USED
- A SHORT TERM REVERSAL OF Ni PRECHARGE CELL DID NOT DAMAGE THE CELL
- NO LONG TERM PROBLEM OF Ni PRECHARGE CELL HAS BEEN IDENTIFIED
- Ni PRECHARGE CELL HAS ADVANTAGE OF LOW OPERATION PRESSURE
- REACTION OF COBALT WITH H₂ MIGHT CAUSE CAPACITY FADING

**NIH₂ BATTERIES AND THEIR
APPARENT VARYING H₂
PRECHARGE**

(NOT SUBMITTED)

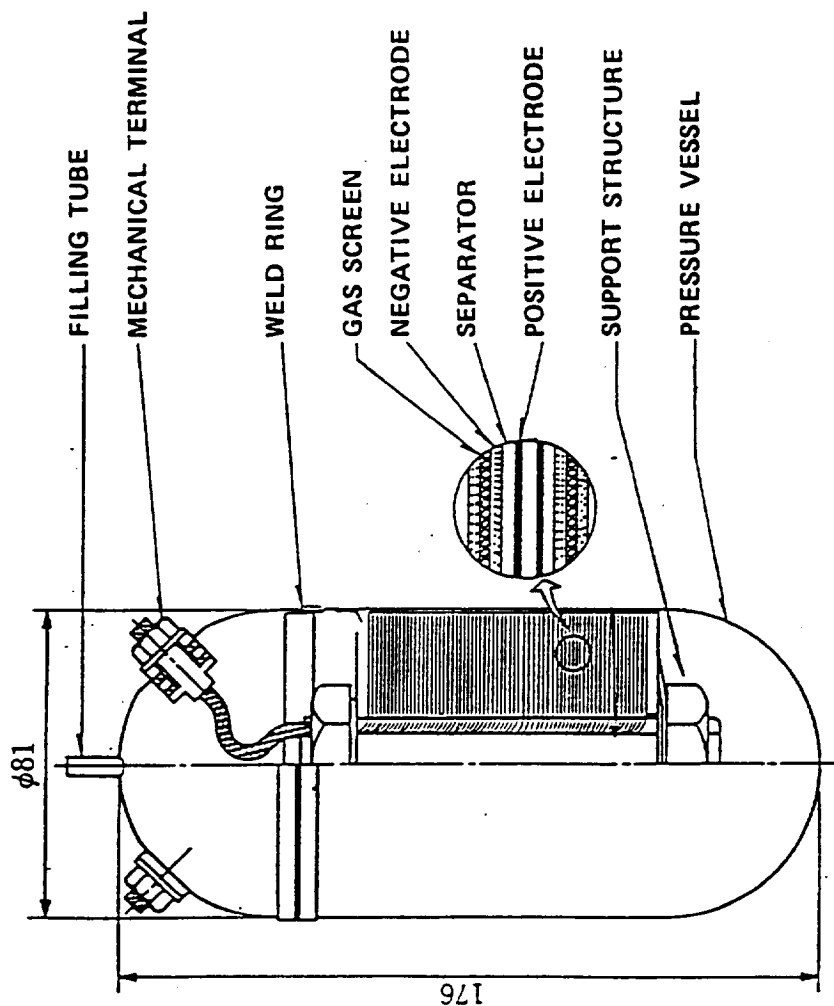
PAUL RITTERMAN, COMSAT

EVALUATION
OF
DEVELOPING Ni-H₂ CELL COMPONENTS

S. KUWAJIMA*, K. YAMAWAKI*
and
M. KANDA**

*National Space Development Agency of Japan
**Toshiba R&D Center, Toshiba Corporation

CONFIGURATION OF Ni-H₂ CELL



MAJOR REQUIREMENTS

CAPACITY	:	35 AH
MISSION	:	10 YEAR
DOD	:	80 %
WEIGHT	:	1000g
LAUNCH YEAR	:	1992

CELL FEATURE

CELL No.	POS. ELEC	NEG. ELEC	SEPARATOR	CELL CASE	STACK	NOTE
BP1	N-STD	H-STD	S-ZA1	BOILOR	1/1 STACK	KOH ELECTROLYTE WITH Li ADDITIVE
BP2				PLATE		
PV1				PRESS.		
PV2		VESSEL		BOILOR PLATE	1/3 STACK	
PV3						
RM1						
RM2						
RM3		H-DP	S-ZA2			
RM4						
RM5						
RM6						
RM7	H-DP	S-TF				
RM8						
RM9						
RM10						
RM11	N-CD3		S-ZA1			
RM12						

ELECTRODE FEATURE

POSITIVE ELECTRODE	N-STD	EI Ni(OH) ₂ WITH Co
	N-CD3	EI Ni(OH) ₂ WITH Co AND Cd
NEGATIVE ELECTRODE	H-STD	Pt CARBON CATALYST LAYER OF SINGLE PORE SIZE
	H-DP	Pt CARBON CATALYST LAYER OF DUAL PORE SIZE
SEPARATOR	S-ZA1	ZIRCONIA-ASBESTOS MONO-LAYER (BUTHYL BINDER)
	S-ZA2	ZIRCONIA-ASBESTOS DUAL-LAYER (BUTHYL BINDER)
	S-TF	ZIRCONIA MONO-LAYER (PTFE BINDER)

SIMULATION TEST CONDITION

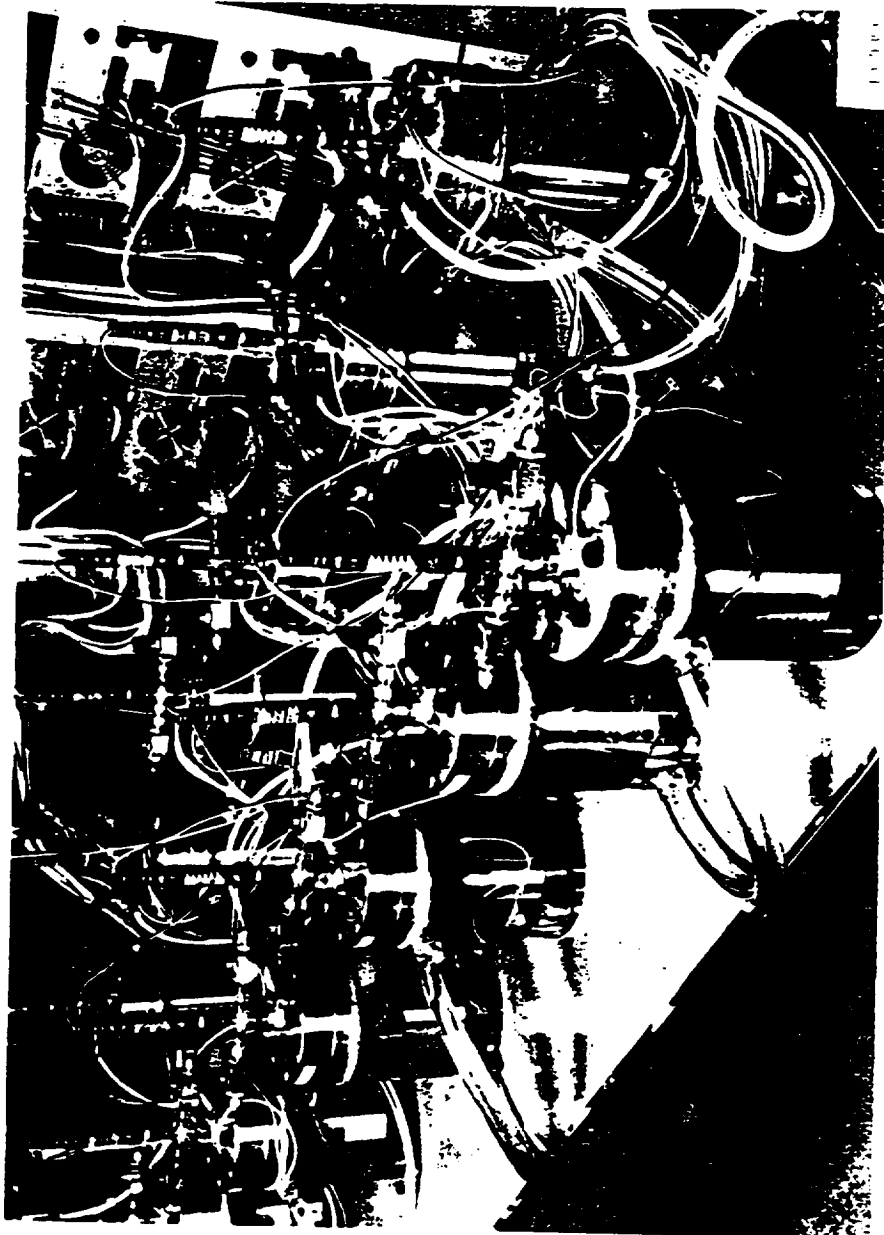
LEO SIMULATION TEST

CHG	0.96 C	55 MIN
DISCHG	1.37 C	35 MIN
DOD	80 %	
CD RATIO	1.1	
TEMP	25 °C	

GEO SIMULATION TEST

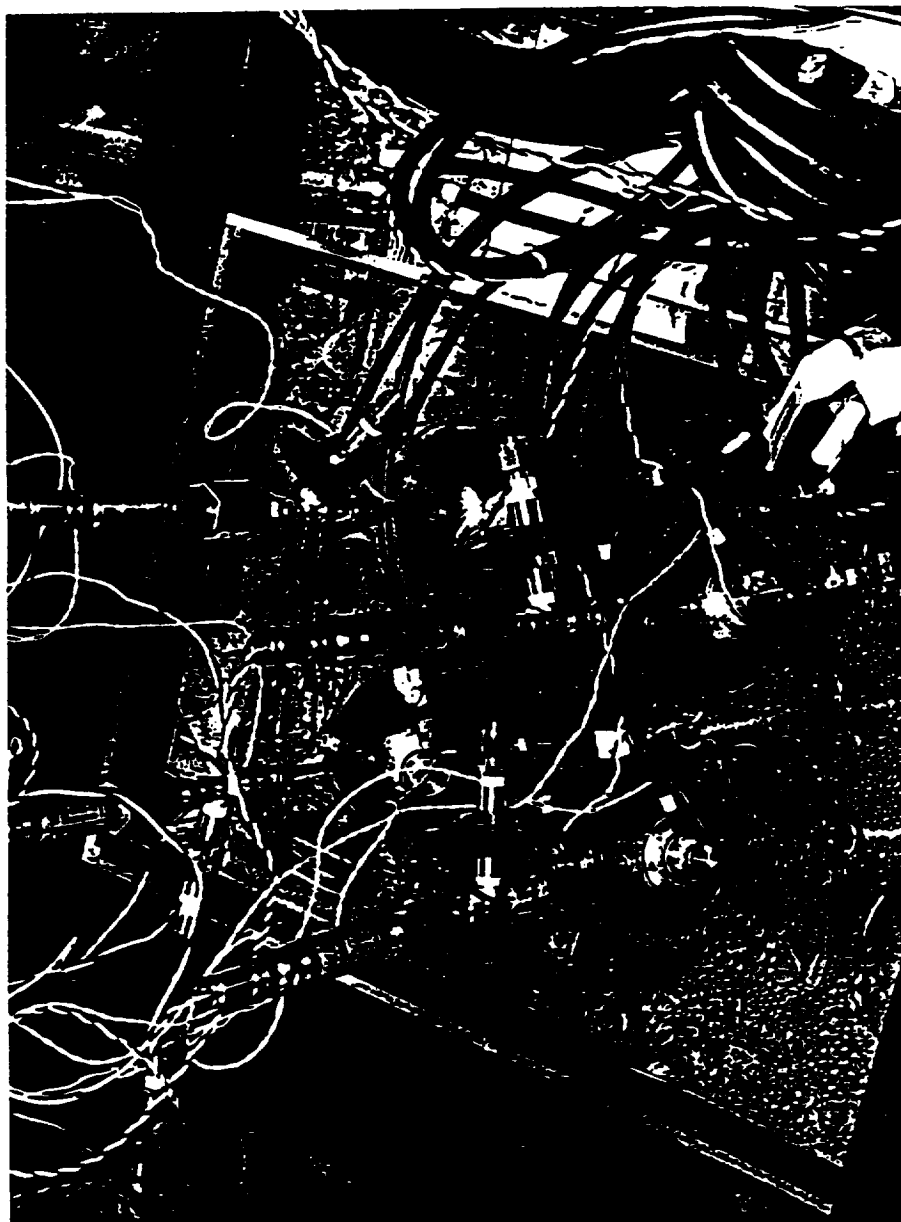
CHG	0.10 C	22.8 HRS
DISCHG	0.67 C	1.2 HRS
DOD	80 %	
TEMP	25 °C	

BOILER PLATE CELL TEST

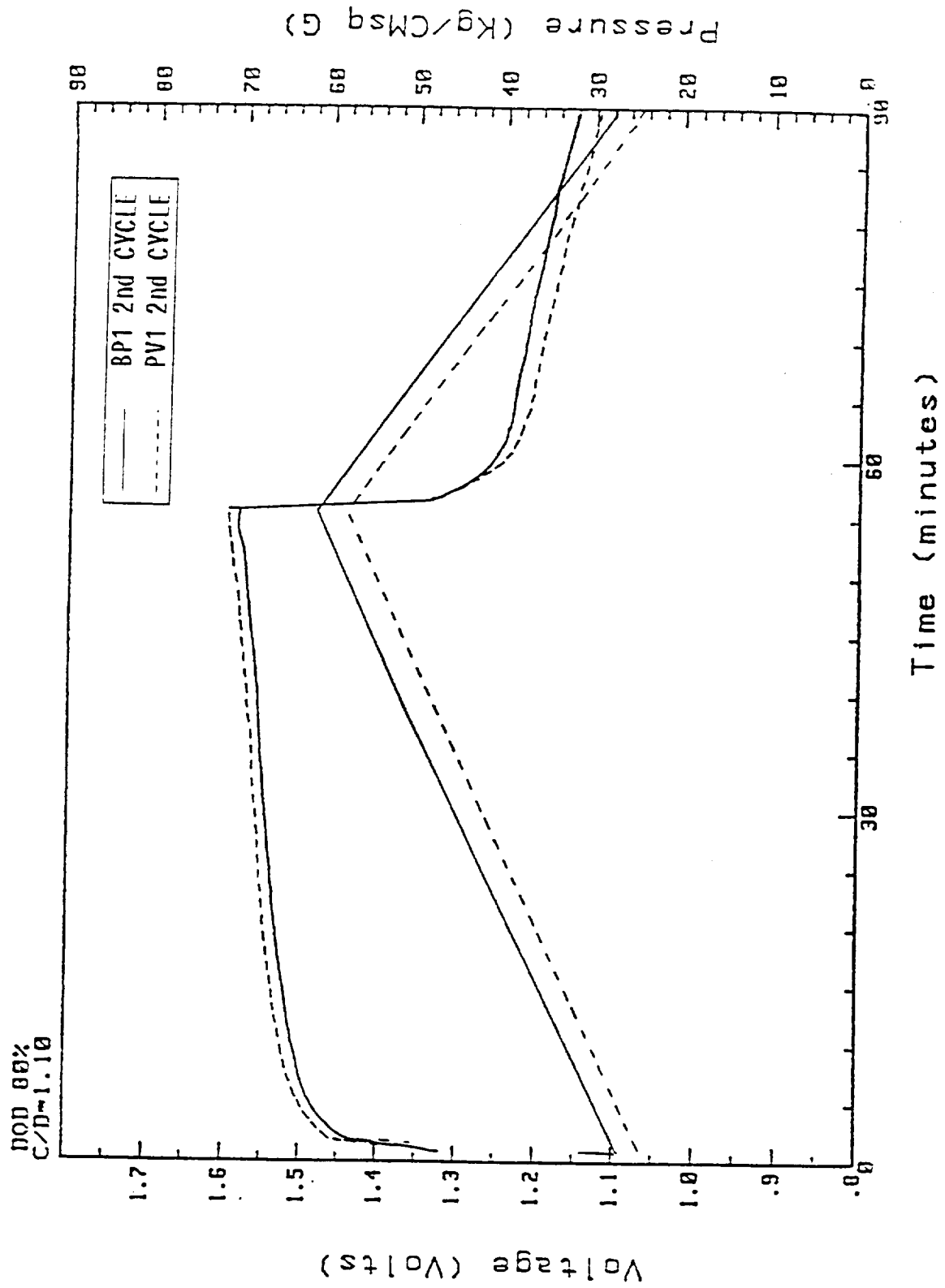


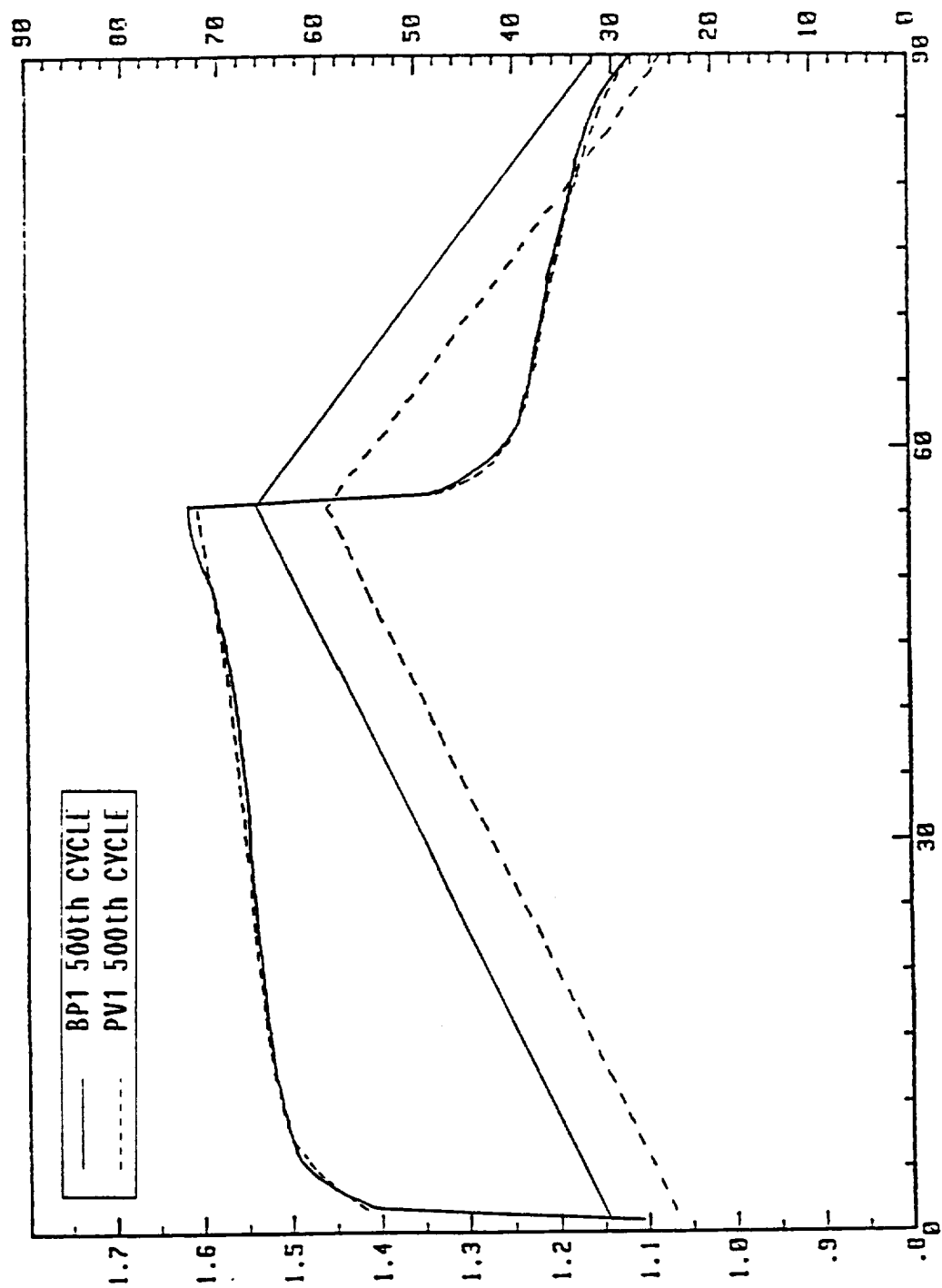
November 1-3, 1988

CELLS UNDER TEST

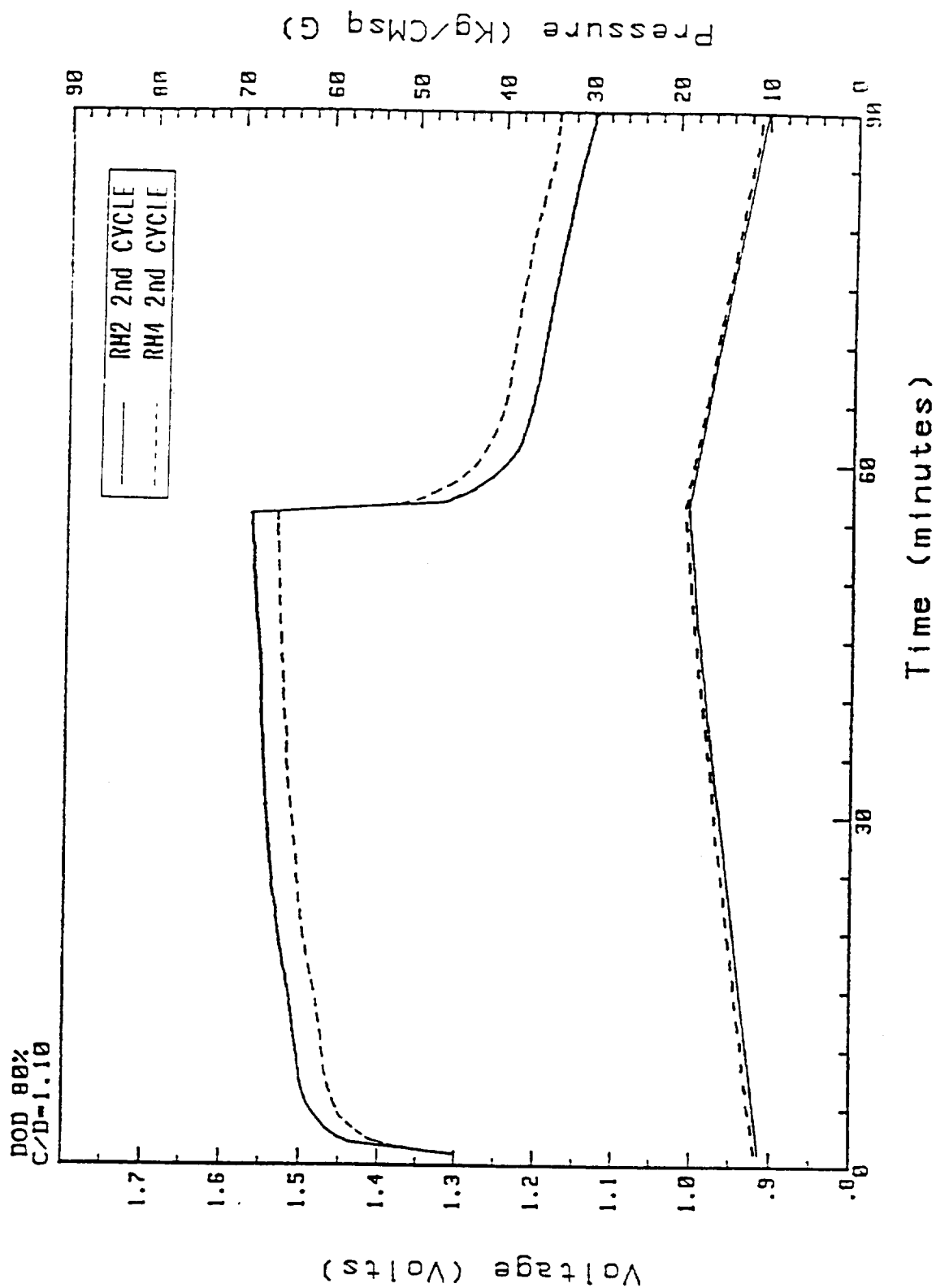


LEO SIMULATION TEST

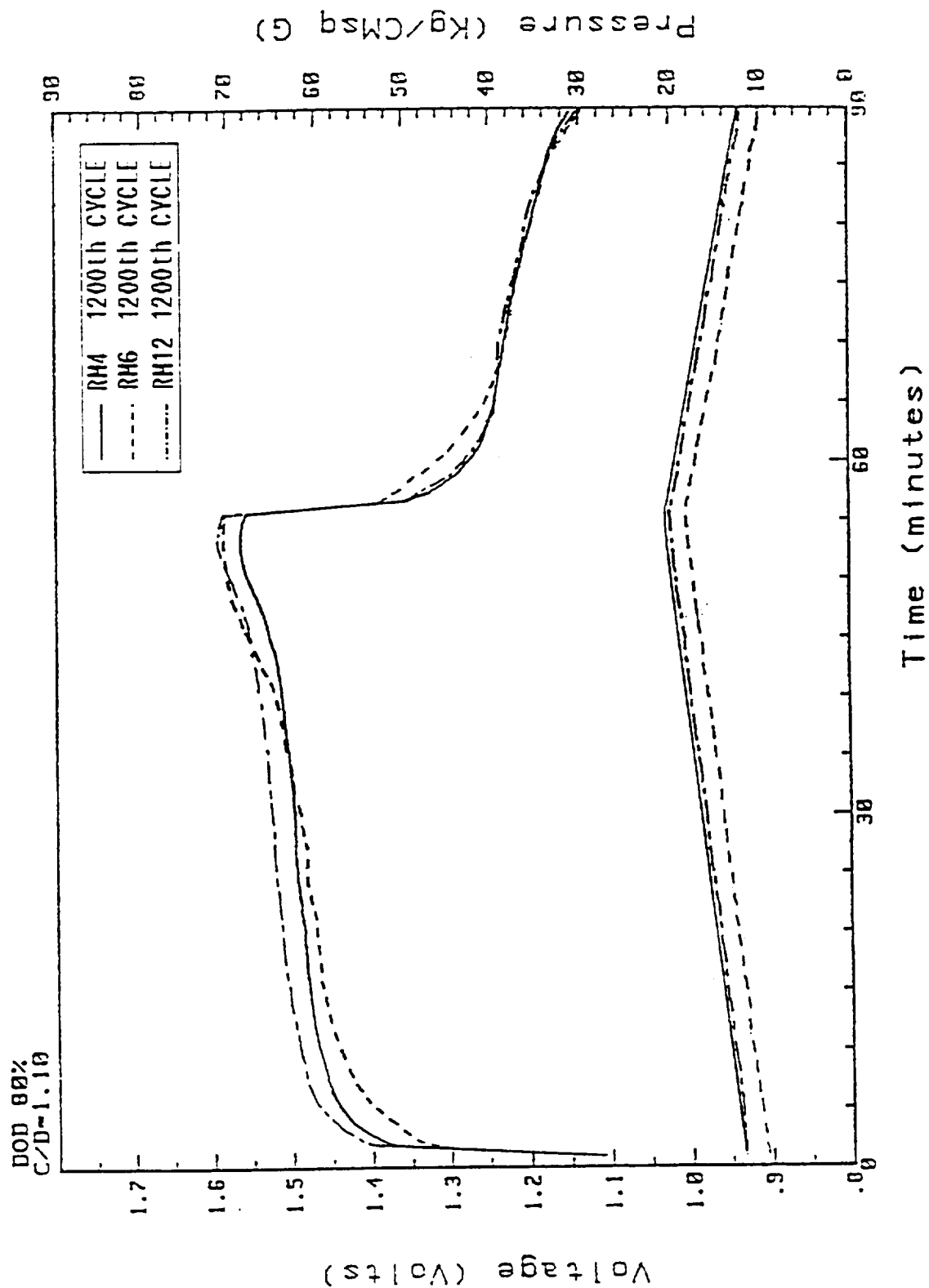




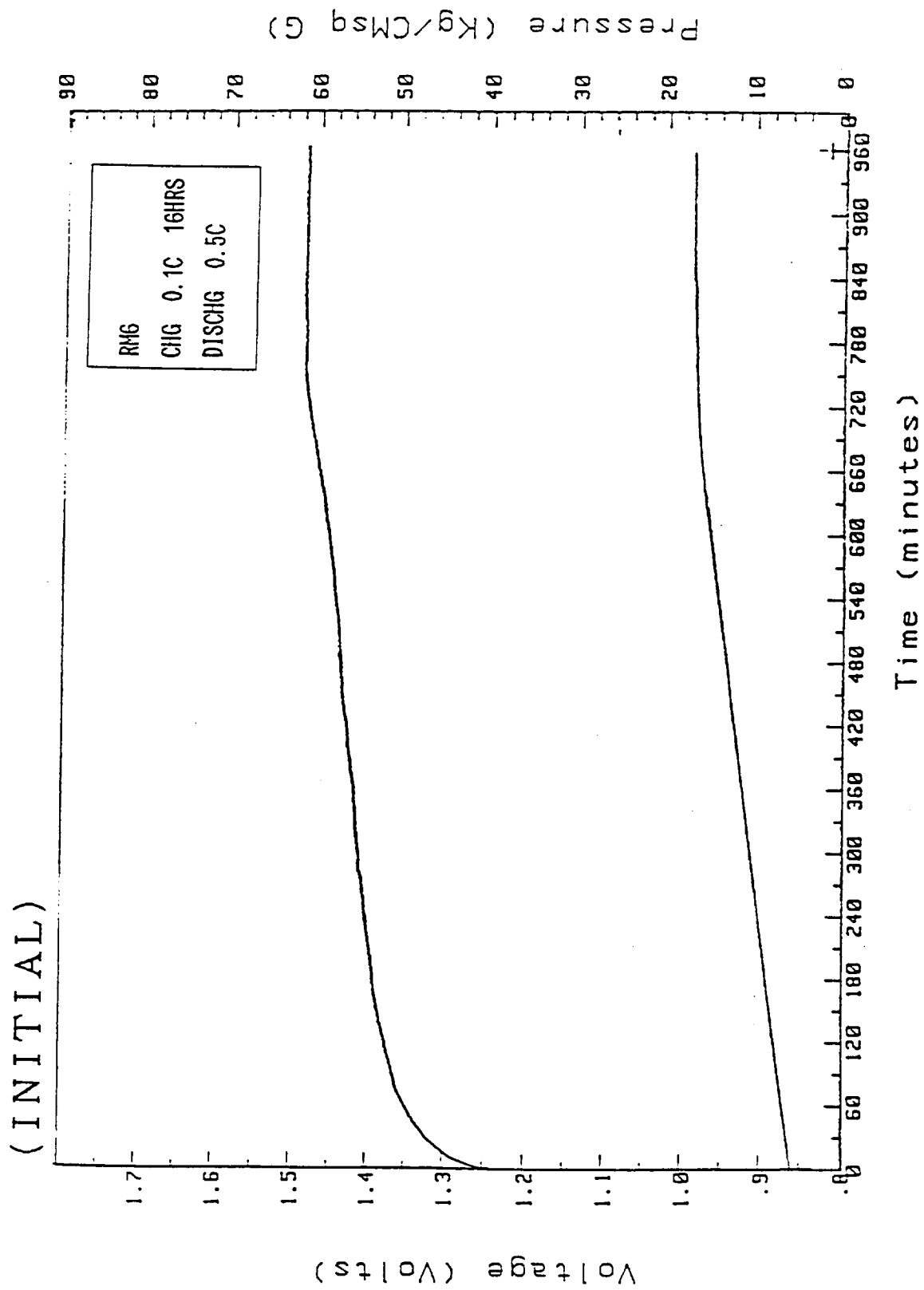
LEO SIMULATION TEST

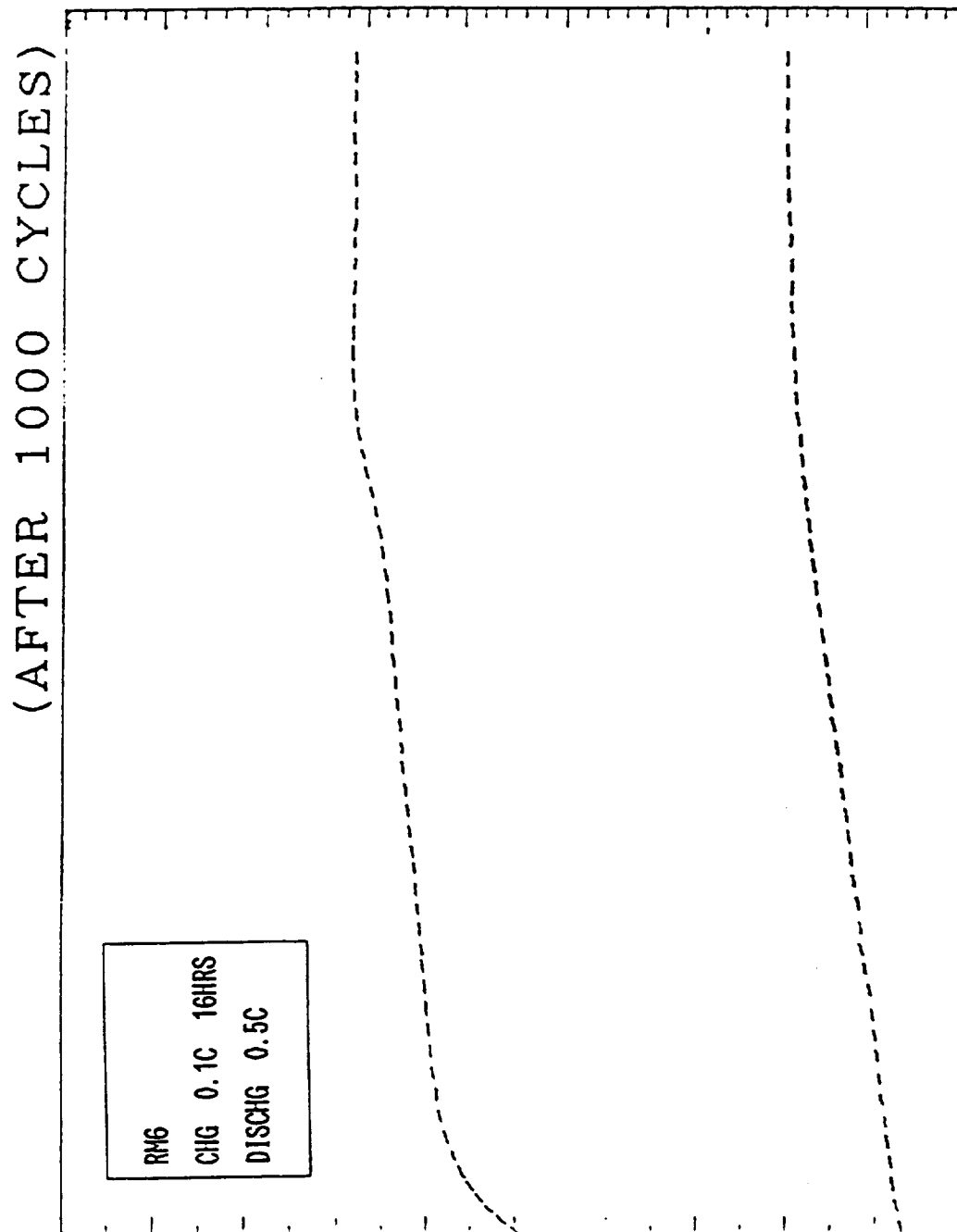


LEO SIMULATION TEST

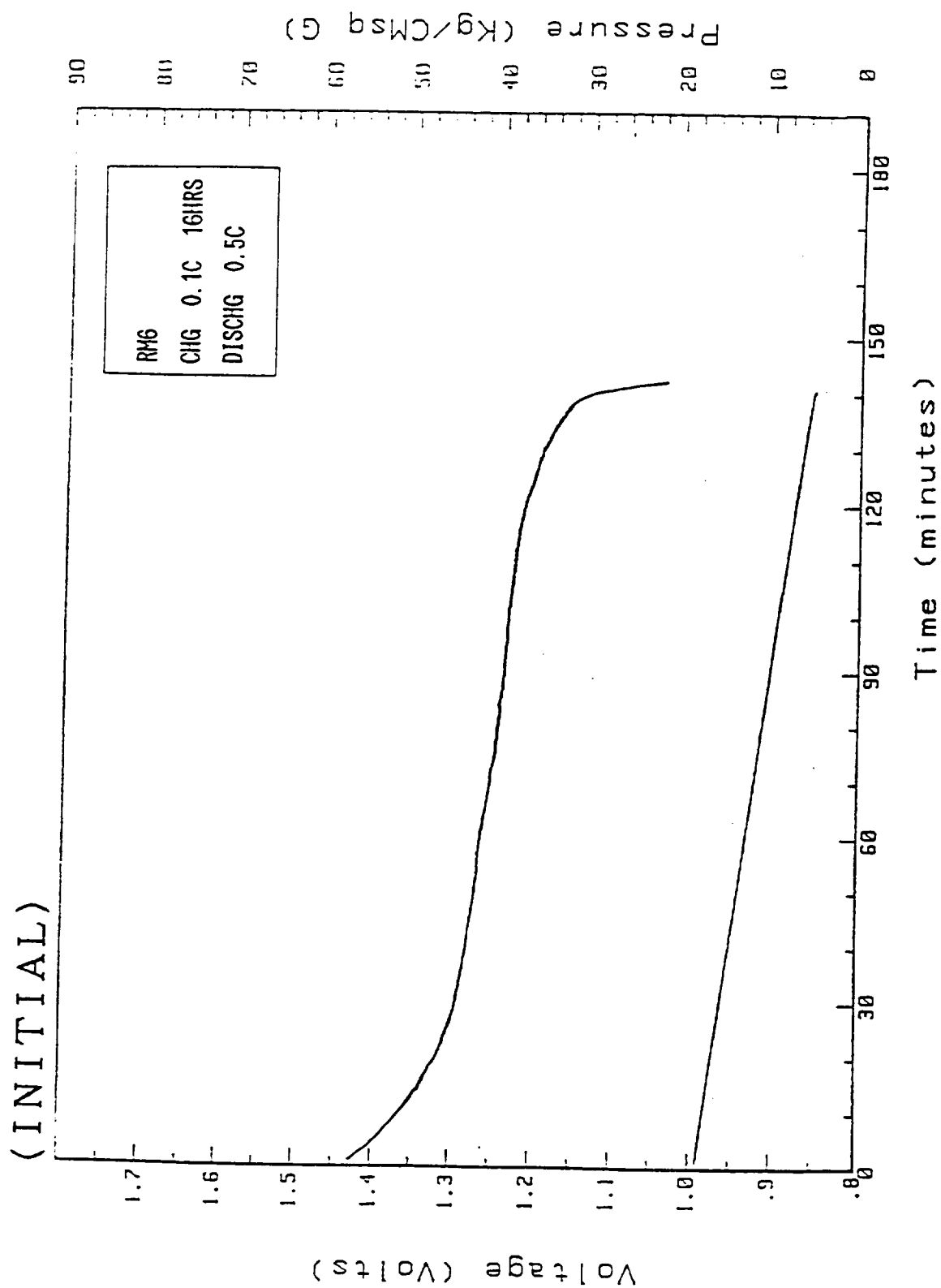


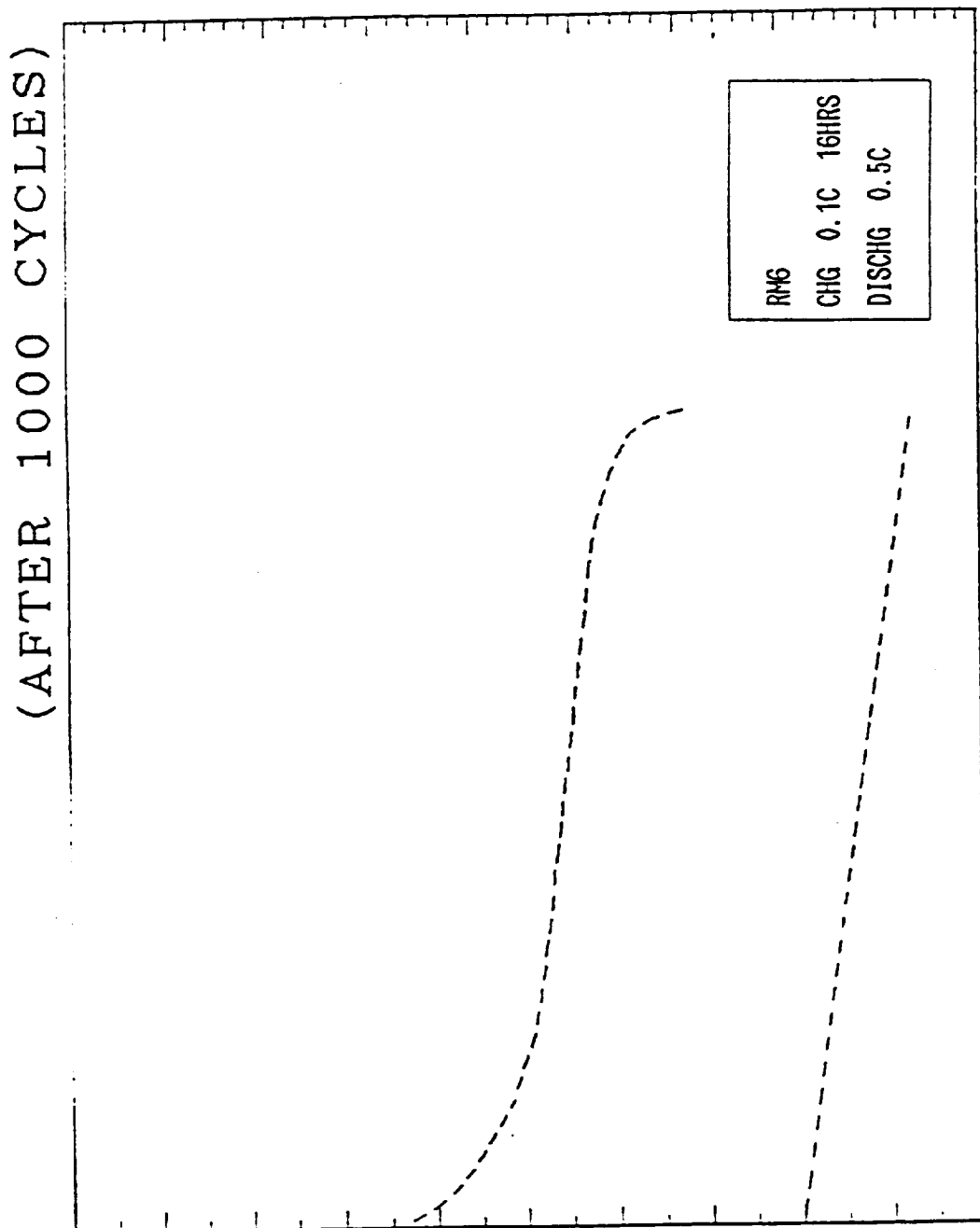
CAPACITY TEST





CAPACITY TEST



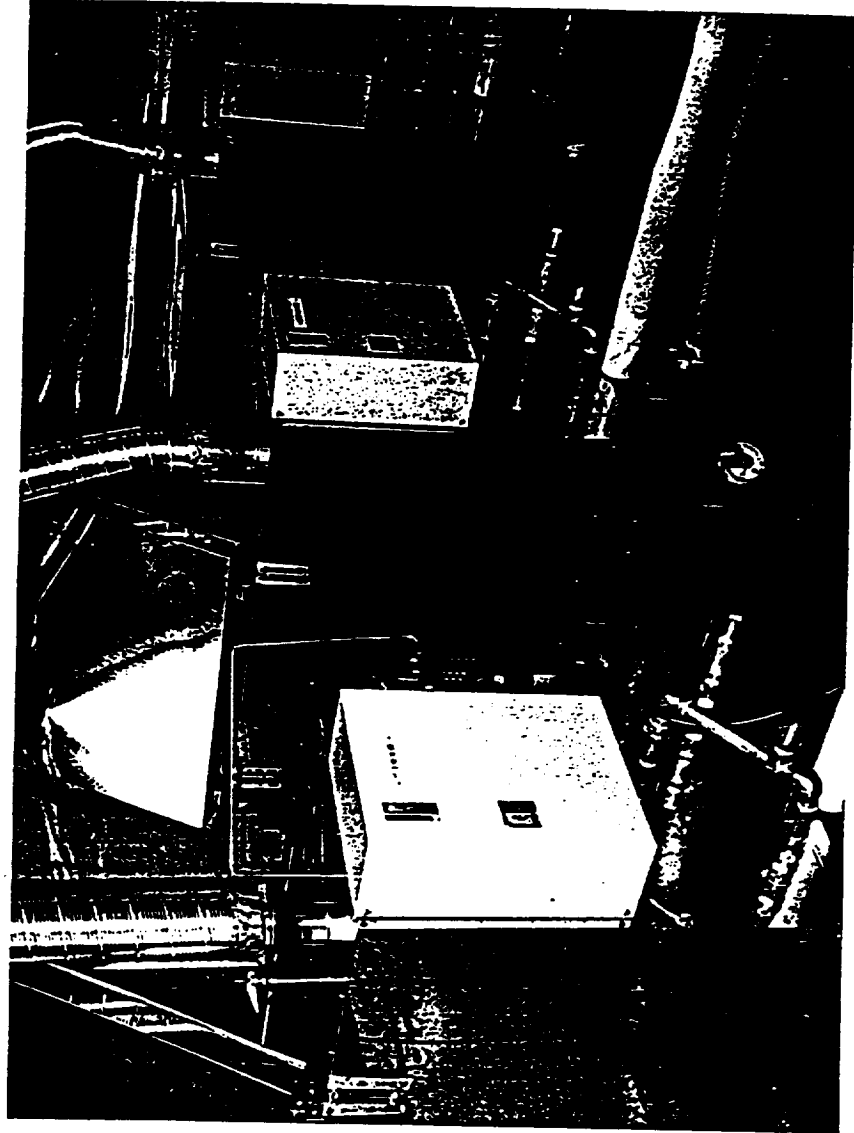


MAIN ISSUES IN Ni-H₂ CELL ELECTROCHEMICAL DESIGN

- * TO MINIMIZE PRESSURE INCREASE AND RESIDUAL HYDROGEN PRESSURE
- * TO MINIMIZE Ni ELECTRODE EXPANSION DURING LEO CYCLING
- * TO MINIMIZE CAPACITY DEPENDENCE ON CHARGE RATE
- * ELIMINATE HOT SPOTS RESULTING FROM RAPID OXYGEN RECOMBINATION

*

TEST CHAMBER



Draft of presentation:

" Evaluation of developing Ni-H₂ cell components" 1988. GSFC/Battery Workshop

Last year, we presented the halfway status of Ni-H₂ cell development in Japan, and mainly showed the results of R&D focused on each component such as electrodes, pressure vessel and terminal.

The mechanical features of Ni-H₂ cell had been specified, and now we are validating the fabrication process of mechanical components and cell.

On the other hand, cell system studies focused on the electrical performance had been initiated at the beginning of this year, succeeding R&D of electrochemical components.

I'm going to present some results of the cycle tests that we are conducting now to specify the electrochemical features of Ni-H₂ cell stack.

Fig. 1

Here are requirements of Ni-H₂ cell and cell configuration.

The requirements explicitly provide only for GEO mission because cell development involved Ni-H₂ battery space experiment on GEO.

However, life of 30,000 cycles at 40% DOD is also expected for LEO applications in the development.

Maximum operating pressure of 70 kg/sq.cm is specified for vessel design.

The cell stack consists of 34 pairs of electrodes with a back-to-back configuration.

To examine the several different kinds of electrodes and separator advanced in preceding R&D, and the effect of some additives, we are evaluating the cells whose electrochemical features are summarized in next figure.

Fig. 2

On the positive electrode, substrate is made of dry sintered nickel porous plaque on nickel screen mesh.

Nickel hydroxide is impregnated on substrate by electrochemical method.

N-STD is a electrode with cobalt hydroxide as a additive.

N-CD3 is a electrode containing cadmium hydroxide as well as cobalt additive.

On the negative electrode, catalyst layer of H-STD is made from mixture with Pt black catalyst and PTFE binder, and is thermally treated after pressed over nickel mesh grid.

H-DP is a electrode containing two different sized pores, large pores of which are formed through thermal decomposition of some agent added to the catalyst layer.

This electrode H-DP showed lower polarization than H-STD as presented later, and become a promising electrode at present.

On the separator, S-ZA1 is a paper made of Buthyl latex binder and fiber mixture which consists of zirconium-oxide and asbestos.

S-ZA2 is a modified paper with dual layer structure.

S-TF uses PTFE instead of Buthyl latex.

The stack of BP1, BP2, RM1 and so on are put into boiler-plate case, which has the same inner diameter as the cell pressure vessel.

PV1, PV2 and PV3 are flight type cells, using developed pressure vessels.

On the other hand, the stack of RM1 and so on consist of 12 pairs of electrode, so approximately one third scale model for those of BP1 and BP2.

Additionally, the potassium hydroxide electrolyte of RM5 and RM6 contains lithium hydroxide as a additive.

Another design parameters such as preload on the stack and hydrogen pre-pressure were set up at the same level in cell assembly process.

Fig. 3

This table briefly summarizes design features of each electrodes and separator.

On the cell evaluations, we are conducting two kinds of cycle test. One means severe cycle regimes, accelerating the conditions of LEO applications. The other simulates the cycle regimes of GEO applications.

Fig. 4

Here are cycle regimes, and we simply call them as LEO and GEO simulation test.

Fig. 5

Concerning temperature control, heat from boiler-plate cells is rejected by circulating coolant around the case wall.

Fig. 6

Flight type cells are put into the test box in which coolant is circulating around the cells. Pressure is measured by transducer connecting fill tube.

Now, I'm going to present some results of cycle tests, especially of LEO cycle. Up to now, GEO cycle tests did not show any distinct results from LEO. This may be due to lower stress for the cell stacks.

Fig. 7

This is a comparison of the initial charge and discharge characteristics of BP1 and PV1, which have the same stack with put into different case. The difference in voltage is mainly due to Ohmic resistances of terminal and so on.

Fig. 8

This is data of BP1 and PV1 at 500 cycles. The pressure increase during the cycle test is about 2 kg/sq.cm on PV1 and about 6 kg/sq.cm on BP1. We consider it is very important issue to limit the pressure increase in Ni-H₂ cell.

Fig. 9

This is data of RM2 and RM4 at 2nd cycle. RM4 used H-DP as negative electrodes, and shows better voltage characteristics than RM2 using H-STD. So, we consider H-DP with two different sized pores is a promising negative electrode.

Fig. 10

This is data of RM4, RM6 and RM12 at 1200 cycles.

RM6 contains lithium hydroxide in electrolyte.

RM12 uses N-CD3 positive electrode containing cadmium hydroxide besides cobalt hydroxide.

We are concerned about Cd migration to negative electrodes in RM12, but there are not any signs of Cd migration from an electrical view point.

The voltage rise of RM6 at the latter part of charge is very clear, and will be convenient to charge control systems.

Fig. 11

This shows charge characteristics of RM6 in initial capacity measurement.

Fig. 12

This is similar data of RM6 after 1000 cycles.

The voltage rise at the latter part of charge occurs about 60 minutes earlier.

And, there is EOC pressure increase of about 1 kg/sq.cm from initial measurement.

Fig.13

This shows discharge characteristics of RM6 in initial capacity measurement.

Fig. 14

This is similar data of RM6 after 1000 cycles.

Discharge time until cell voltage reached 1.0 volt is about 10 minutes shorter, but there are not found any degradations in voltage.

Now we are fabricating the 16 flight type cells for EM space experiment battery. These cells have the same electrochemical features as RM6, which has indicated good performance up to now.

However, we have about one year until specifying the design features of a space experiment cell.

So, we will continue system studies including DPA of cells now under testing and the cell evaluations with newly advanced features, in order to improve the Ni-H₂ cell performance.

Fig.15

At the end, this summarizes main issues we have to take measures with the cell evaluations.

THE EVALUATION OF NEW NICKEL-HYDROGEN BATTERY SEPARATORS IN BOILERPLATE CELLS

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BACKGROUND

- REPLACEMENT SEPARATOR FOR ASBESTOS IS DESIRABLE
- HIGH BUBBLE PRESSURE, LOW RESISTIVITY, GOOD ELECTROLYTE RETENTION REQUIRED
- POTASSIUM TITANATE-POLYETHYLENE BLEND DEVELOPED
- RADIATION-GRAFTED POLYETHYLENE FILM AVAILABLE
- SCREENING TESTS VERIFIED NECESSARY CHARACTERISTICS
- BOILERPLATE CELLS ASSEMBLED AND TESTED IN-HOUSE

OBJECTIVES

- COMPARE PERFORMANCES OF CELLS BUILT WITH BLENDED POTASSIUM TITANATE-POLYETHYLENE SEPARATORS AND WITH ZIRCAR CLOTH/RADIATION-GRAFTED POLYETHYLENE FILM SEPARATORS TO CELLS BUILT WITH ASBESTOS SEPARATORS.
- EVALUATE SEPARATOR INTEGRITY FOLLOWING CYCLING.

APPROACH

- BUILD THREE, THREE AMPERE HOUR CELLS FROM EACH OF THE THREE SEPARATOR MATERIALS
- CHARACTERIZATION CYCLE UP TO THE 2 C RATE
- LEO CYCLE FOR 2,000 CYCLES
- DISASSEMBLE CELLS AND EVALUATE THE SEPARATORS AND OTHER COMPONENTS



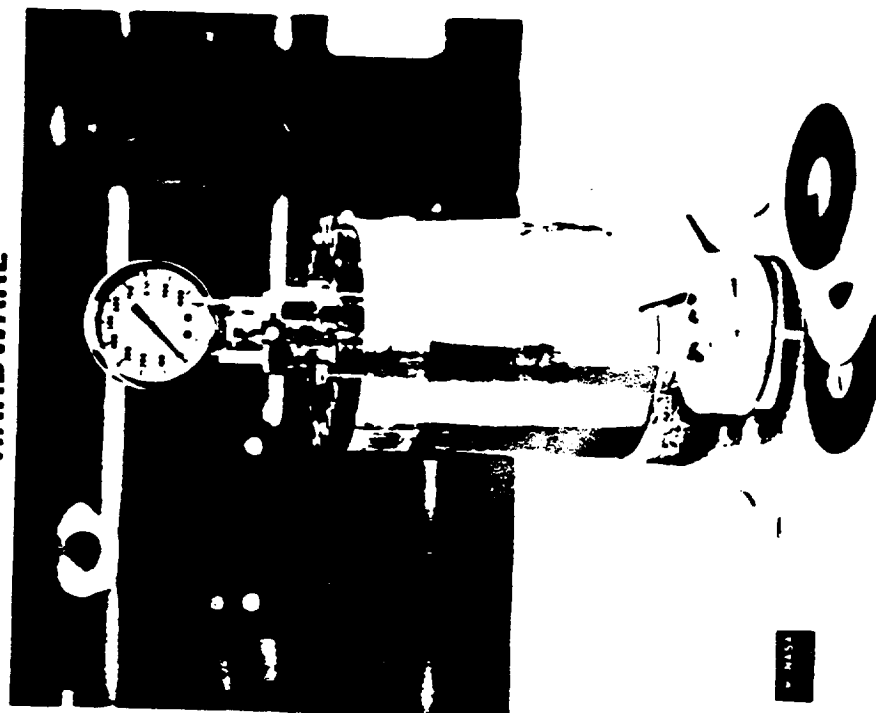
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NICKEL-HYDROGEN BOILERPLATE CELL STUDIES

HARDWARE



PURPOSE

DESIGN VERIFICATION
COMPONENT EVALUATION
SIMULATE CYCLING MODES

FEATURES

IN-HOUSE CAPABILITY
EASE OF ASSEMBLY
REUSABLE HARDWARE
COST EFFECTIVE

CD-88-37692

MID-DISCHARGE VOLTAGES AFTER 2000 LEO CYCLES

80% DOD, C/D = 1.10, 1.37 C DISCHARGE

<u>CELL</u>	<u>SEPARATOR</u>	<u>VOLTAGE, VOLTS</u>
1	ASBESTOS	1.193
2	"	1.229
3	"	1.229
4	POTASSIUM TITANATE-POLYETHYLENE	1.229
5	"	1.240
6	"	1.254
7	ZIRCAR CLOTH AND POLYETHYLENE FILM	1.253
8	"	1.225
9	"	1.210

POSTTEST CELL OBSERVATIONS

CELL	SEPARATOR		CELL CORE	H ₂ ELECTRODE
	TYPE	APPEARANCE		
1	ASBESTOS	NORMAL	LOOSE	GOOD CONDITION
2	"	"	"	"
3	"	"	INTACT, BUT NOT TIGHT	"
4	PKT-PE	INTACT, SOME ADHESION TO H ₂ AND Ni ELECTRODES	LOOSE FINE WHITE RESIDUE	SOME FLOODING APPARENT
5	"	"	INTACT, BUT NOT TIGHT FINE WHITE RESIDUE	BURNED AREAS ON TWO ELECTRODES
6	"	"	LOOSE FINE WHITE RESIDUE	BURNED AREAS ON ONE ELECTRODE
7	ZIRCAR/PE	ZIRCAR - VERY MOIST PE - UNCHANGED	INTACT, BUT NOT TIGHT	GOOD CONDITION
8	"	"	LOOSE Ni RESIDUE	"
9	"	"	LOOSE Ni RESIDUE	"



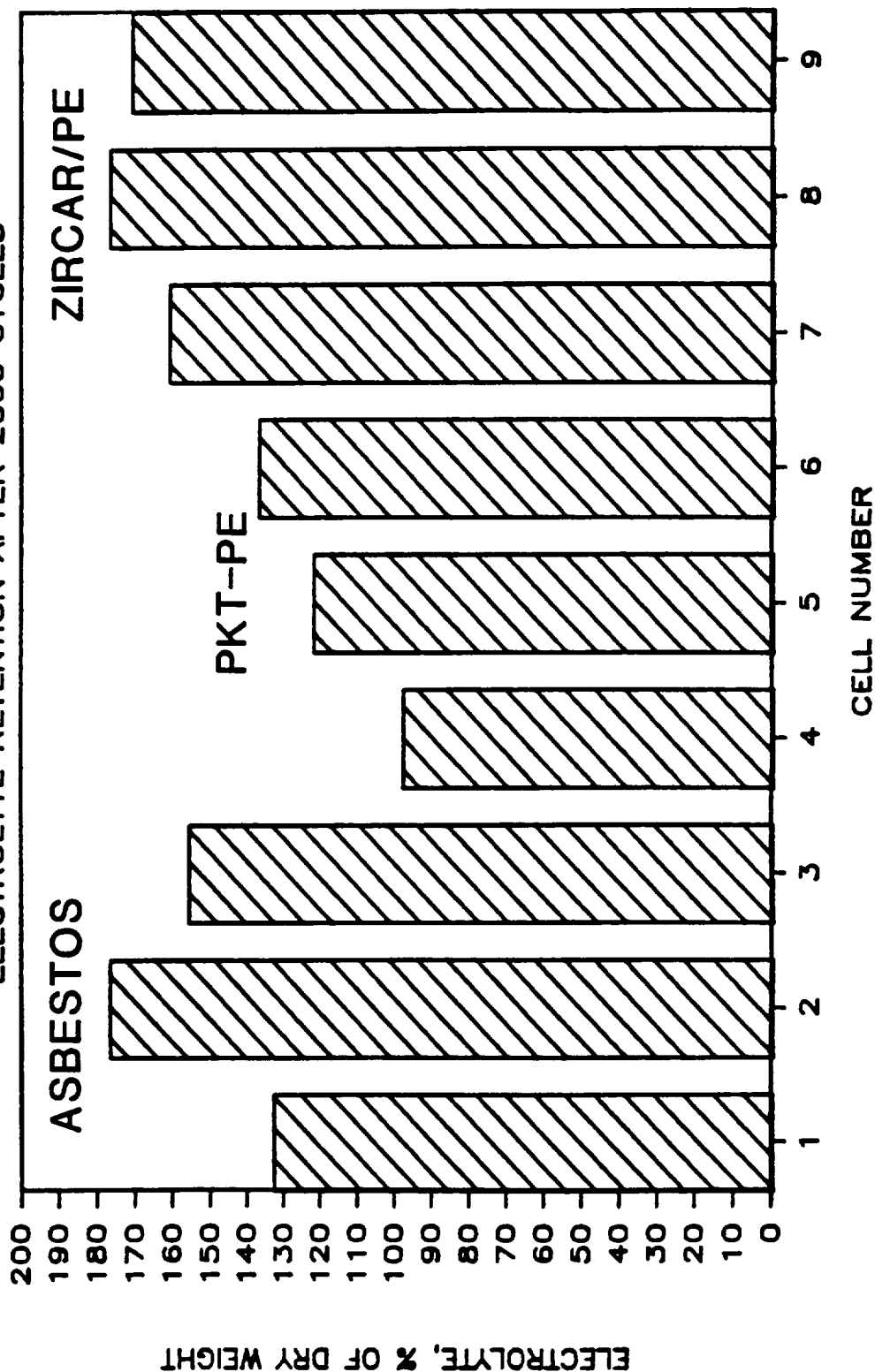
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POSTTEST SEPARATOR WEIGHT ANALYSIS

ELECTROLYTE RETENTION AFTER 2000 CYCLES



SUMMARY AND CONCLUSIONS

- TWO NEW SEPARATOR CONCEPTS WERE TESTED IN BOILERPLATE CELLS BY CHARACTERIZATION CYCLING TO 2 C AND LEO CYCLING FOR 2000 CYCLES
- PERFORMANCES OF POTASSIUM TITANATE-POLYETHYLENE CELLS AND ZIRCAR/POLYETHYLENE FILM CELLS WERE COMPARABLE TO ASBESTOS CELLS
- SEVERAL POTASSIUM TITANATE-POLYETHYLENE SEPARATORS APPEARED TO ALLOW OXYGEN PASSAGE
- ZIRCAR CLOTH/POLYETHYLENE FILM SEPARATOR WARRANTS FURTHER EVALUATION IN FLIGHT WEIGHT CELLS

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